AFRL-SN-WP-TR-2001-1037

TECHNICAL SUPPORT AND ADVISORY AND ASSISTANCE SERVICES (A&AS) FOR THE ADVISORY GROUP ON ELECTRON DEVICES (AGED) AND THE DEFENSE SCIENCE AND TECHNOLOGY RELIANCE

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APRIL 2001

FINAL REPORT FOR PERIOD OF 05 FEBRUARY 1997 – 30 SEPTEMBER 2000

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
APRIL 2001

3. REPORT TYPE AND DATES COVERED
Final, 02/05/1997 – 09/30/2000

4. TITLE AND SUBTITLE

TECHNICAL SUPPORT AND ADVISORY AND ASSISTANCE SERVICES (A&AS) FOR THE ADVISORY GROUP ON ELECTRON DEVICES (AGED) AND THE DEFENSE SCIENCE AND TECHNOLOGY RELIANCE

5. FUNDING NUMBERS
C: F33615-97-C-1007
PE: 62204F
PN: 2202
TN: 06
WU: 02

6. AUTHOR(S)

ELLIOT COHEN

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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10. SPONSORING / MONITORING AGENCY REPORT NUMBER

AFRL-SN-WP-TR-2001-1037

11. SUPPLEMENTARY NOTES:

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 Words)***

Palisades provided technical (scientific and economic) assessments of government, industrial, and academic programs and management/administrative recommendations for efforts related to electronics in support of the Advisory Group on Electron Devices (AGED). This support included preparing a substantial amount of briefing material for use by the executive director of AGED during technical area review and assessment (TARA) meetings.

14. SUBJECT TERMS
Advisory Group on Electron Devices, Microwaves, Micro Electronics, Electro-Optics

15. NUMBER OF PAGES
232

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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1. INTRODUCTION AND SUMMARY

For over 30 years, Palisades Institute for Research Services, Inc. (Palisades) has provided technical, managerial, and administrative support to the Office of the Secretary of Defense's Advisory Group on Electron Devices (AGED). The AGED is a 55-year-old DoD advisory body constituted under the Federal Advisory Committee Act. It reports to the Director of Defense, Research and Engineering. Its organization consists of a main group and three subgroups (microwaves, microelectronics, and electro-optics) of technical experts from government, industry, and academia. The AGED serves as a forum for all of the armed services, the Defense Advanced Research Projects Agency (DARPA), the Defense Threat Reduction Agency (DTRA), the Ballistic Missile Defense Organization (BMDO), the National Aeronautics & Space Administration (NASA) and other government agencies. Its members and participants discuss electronics issues and programs and contribute to the process of planning new programs and initiatives of importance to the Department of Defense (DoD). The AGED provides a reliable, current source of expert information and guidance about electron device and electro-optics technologies that are used in DoD weapon systems.

The AGED's objectives are to develop the best investment strategy for the DoD electron device program and identify and explore serious electronics issues requiring Office of the Director, Defense Research & Engineering (ODDR&E) attention. It assists the DoD Reliance Technical Panel on Electron Devices (TPED) in its efforts to efficiently meet the electronics needs of all services by identifying electronics investment areas of critical importance for all of the services and supporting the Technical Area Review and Assessment (TARA) process for electronics. The AGED serves as an honest broker, facilitating coordination and synergism among DoD components and other agencies.

During the period of performance of Contract No. F33615-97-C-1007, February 5, 1997 through September 30, 2000, Palisades provided technical (scientific and economic) assessments of government, industrial, and academic programs and management/administrative recommendations for efforts related to electronics in support of the AGED, the AGED Executive Director, the Defense Science & Technology (S&T) Reliance, the Defense Technology Area Plan (DTAP) Panels, the TARA team for electronics, and the related TPED. The Palisades' program manager for the work performed under this contract was Mr. Eliot D. Cohen, Corporate Vice President and Executive Director of Technical Operations. Palisades' staff members who actively participated on the contract were Mrs. Joy Baumgarten, Mrs. Janice Brooks, Mr. Eric Carr, Mr. David Cox, Mr. Timothy Doyle, and Ms. Elise Rabin. Palisades' performance on this contract has been monitored by the Contracting Officer's Technical Representative (COTR), Mr. Mark Pacer, Air Force Research Laboratory (AFRL), Wright-Patterson AFB, OH.

During the period of performance of this contract, Palisades carried out the following responsibilities:

- Provided technical and administrative support for advisory group (main group), working group, and TPED meetings, including preparing written summaries in the form of minutes of those proceedings, as well as technology assessment reports pursuant to assisting in the

review and oversight of government-sponsored electron device research and development (R&D) programs.

- Prepared agendas for main group, working groups, and TPED meetings based on technical and programmatic information provided by tri-service/NASA members and relevant material obtained from the ODDR&E and other government agencies (e.g., DARPA, the National Security Agency, the Central Intelligence Agency, the National Institute of Standards and Technology) concerned with electron device development and deployment. Also provided on a regular basis was additional information bearing on technology, funding and policy issues from the *Commerce Business Daily*, general open literature, the Defense Technical Information Center, technical conferences and symposia and other sources from industry and government and academia. At the beginning of each AGED meeting, AGED members and participants were provided with a summary of technical papers germane to current AGED-related issues. This reference material was culled from a large body of technical literature reviewed by the Palisades' staff.
- Developed and maintained password-protected AGED and TPED Internet sites to allow AGED and TPED members to (1) transact AGED- and TPED-related business in the time interval between meetings, (2) communicate among themselves and with the Secretariat on a real-time basis as important issues arose, and (3) access the Secretariat's databases on electron device technology.
- Maintained AGED/TPED databases of technical and financial information on electronics R&D programs (contractual and in-house). .
- Arranged, supported, and documented the TARA of the DoD electronics S&T program (formerly the Science and Technology Review), and assisted in the preparation of the resulting TARA report.
- Assisted the AGED and TPED in organizing and preparing programs for Special Technology Area Reviews (STARs), AGED workshops, and other AGED- and TPED-sponsored meetings and conferences. Palisades' personnel edited and reviewed every STAR report and, in many cases, wrote concise, accurate executive summaries of them.
- Reviewed and analyzed technical reports and studies submitted by industry and government agencies for technical and management significance, and provided continuous consultation on leading-edge electronics technology.
- Provided special status reports for management review on particular problem areas and potentially important breakthroughs.
- Acted as technical liaison to and among ODDR&E, AGED, and the Defense S&T Reliance/TPED organizations.
- Provided support as necessary to advance the mission of the AGED and the Defense S&T Reliance/TPED organization.

Figure 1 is a roadmap of selected activities performed as part of the Technical Support and Advisory and Assistance Services (A&AS) for the AGED and the Defense S&T Reliance TPED.

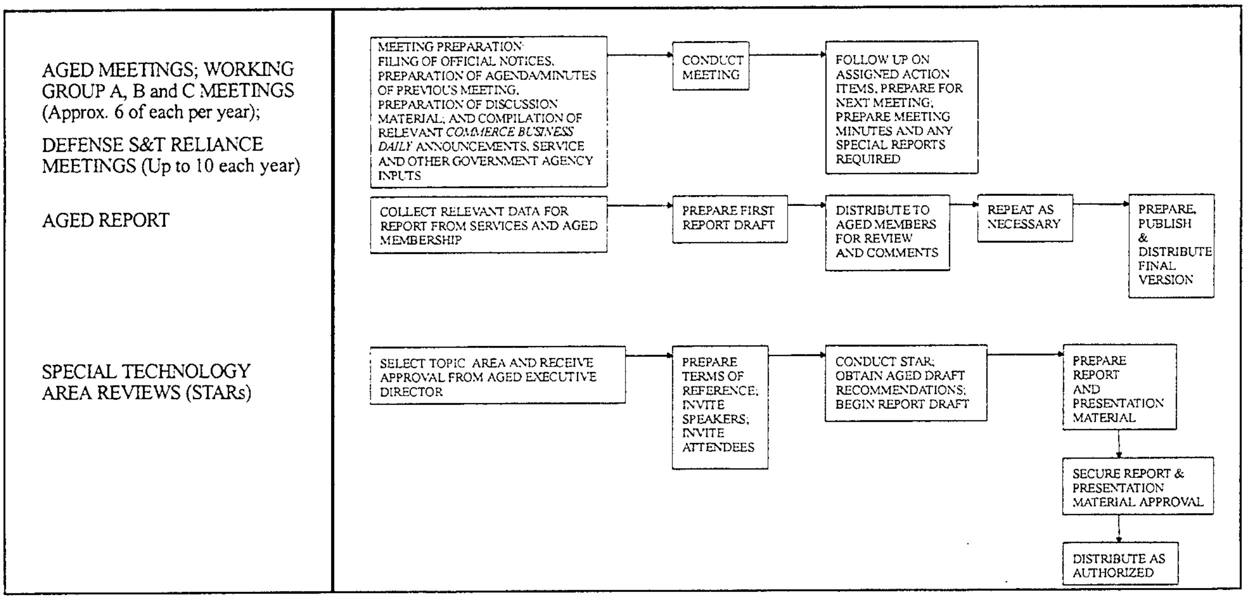

Figure 1. Roadmap of Selected Activities

2. WORK PERFORMED UNDER CONTRACT F33615-97-C-1007

Palisades has provided technical, engineering and administrative support services for the DoD AGED, the AGED Executive Director, and the Defense S&T Reliance, including the DTAP Panels, the TARA Team for Electronics and the TPED. Details of Palisades' services provided under this contract are described in the narrative, which follows.

2.1 Meeting Support

2.1.1 AGED Meeting Support

Palisades' prepared meeting notices, Federal Register notices, agendas and minutes for the following AGED Meetings. It also hosted all of these meetings at its Crystal City, VA facilities, providing full meeting support services, except as noted below.

Main Group	Working Group A (Microwaves)	Working Group B (Microelectronics)	Working Group C (Electro-optics)
April 9, 1997	February 5, 1997	February 6, 1997	March 26, 1997
June 6; 1997	April 8, 1997	April 10, 1997	May 28-29, 1997[6]
October 6, 1997	June 3, 1997	June 5, 1997	August 19-20, 1997[7]
December 10, 1997	September 10, 1997	September 18, 1997	November 18, 1997
February 18, 1998	December 9, 1997	December 12, 1997	January 21-22, 1998
April 22, 1998	February 17, 1998	February 3-4, 1998[5]	April 1, 1998
June 16, 1998	May 14, 1998[3]	April 28, 1998	June 3-4, 1998
September 10, 1998	July 15, 1998	June 11, 1998	August 24-25, 1998
November 20, 1998	September 9, 1998	September 11, 1998	November 4-5, 1998[8]
January 20, 1999	November 19, 1998	November 19, 1998	January 21, 1999
March 17, 1999	January 19, 1999	January 22, 1999	March 23, 1999
May 26, 1999	March 16, 1999	March 18, 1999	July 1, 1999
July 21, 1999	May 27, 1999	May 25, 1999	September 16, 1999
September 23, 1999	July 20, 1999	July 22, 1999	December 9, 1999
November 18, 1999[1]	September 22, 1999	October 21, 1999	February 29, 2000
January 19, 2000	November 17, 1999	January 20, 2000	May 18, 2000
March 15, 2000	January 18, 2000	April 25, 2000	August 8-9, 2000[2]
May 24, 2000	March 14, 2000[4]	August 8-9, 2000[2]	
August 8-9, 2000[2]	April 28, 2000	September 28, 2000	
September 27, 2000	June 7, 2000		
	August 8-9, 2000[2]		
	September 11, 2000		

[1]Held at U.S. Army Research Laboratory, Adelphi, MD
[2]AGED Forum, held at the Georgetown University Conference Center, Washington, DC; all AGED groups participated
[3]Held at Hyatt Regency Hotel, Monterey, CA
[4]Held at Rosslyn Plaza North, Rosslyn, VA
[5]Held at Air Force Phillips Laboratory & Sandia National Laboratories, Albuquerque, NM
[6]Held at Naval Command, Control and Ocean Surveillance Center, San Diego, CA
[7]Held at Rome Laboratory, Hanscom AFB, MA
[8]Held at U.S. Army CECOM-RDEC, Night Vision & Electronic Sensors Directorate, Ft. Belvoir, VA

2.1.2 TPED Meeting Support

Palisades prepared agendas and minutes for the following TPED meetings. It hosted them at its Crystal City, VA facilities, except as otherwise noted.

July 30, 1997
August 14, 1997
October 21-23, 1997
June 16, 1998
July 10, 1998
August 11, 1998
September 10, 1998
October 28, 1998
November 24, 1998
December 15, 1998
January 20, 1999
May 26, 1999
July 21, 1999
August 4, 1999
September 23, 1999
October 18, 1999
November 18, 1999[1]
January 12, 2000
February 23, 2000[2]
March 22, 2000[3]
May 23, 2000[1]

[1]Held at U.S. Army Research Laboratory, Adelphi, MD
[2]Held at U.S. Air Force Research Laboratory, Kirtland AFB, NM
[3]Held in conjunction with the GOMAC/HEART Conference, Anaheim, CA

2.1.3 (Electronics) TARA Meeting Support

Palisades provided full technical and administrative support for the following TARAs held during the period of performance for this contract:

- March 17-21, 1997 at the Naval Research Laboratory, Washington, DC
- March 9-13, 1998 at the Naval Research Laboratory, Washington, DC
- March 1-5, 1999 at the Naval Postgraduate School, Monterey, CA

This support included preparing a substantial amount of briefing material for use by the Executive Director of the AGED during the TARA meetings; editing, arranging, reproducing and shipping thousands of pages of briefing material for use by the TARA team members prior to and during the TARA meetings; providing technical and administrative support to the TARA team, the AGED Executive Director and other participants prior to, during, and after the TARA meetings; and collecting, compiling, and preparing charts and graphs of financial information about the DoD S&T electronics program. The source of the financial information was the Palisades' financial database. This database not only provides a historical record of DoD expenditures on electronics S&T projects but also is constantly updated as new financial

information is received from the services and DoD agencies, such as DARPA and DTRA. The information was used by the TARA team and AGED Executive Director during the TARA and serves as a reference source used by the Office of the Secretary of Defense (OSD), the services, and DoD agencies throughout the year. Palisades also assisted the Executive Director of AGED in the preparation of her TARA outbriefs to the Defense Science and Technology Advisory Group (DSTAG), subsequent to the TARA meetings.

2.1.4 STARs

Palisades provided technical and administrative support for the following STARs during the contractual period of performance. This included preparing agendas, inviting speakers, organizing and conducting the STARs, and helping in preparation of the STAR reports generated at or emanating from the following:

- Micro-Opto-Electro-Mechanical Systems (MOEMS), held May 28 to 29, 1997 at the Naval Command Control and Ocean Surveillance Center/Naval Research and Development (NCCOSC/NraD), San Diego, CA
- Mixed Signal Components (Part 1), held September 17, 1997 at Palisades
- Commercial-Off-The-Shelf (COTS) Electronics, held, December 4 to 5, 1997 at the Naval Research Laboratory (NRL), Washington, DC
- Mixed Signal Components (Part 2), held December 11, 1997 at Palisades
- Infrared Countermeasure Lasers, held June 3 to 4, 1998 at Palisades
- Reliability of Electron Devices for Defense Applications, held February 23, 1999 at Palisades
- Low Cost Lasers, held September 14 to 15, 1999 at Palisades
- Packaging, held October 19 to 20, 1999 at Palisades
- Radio Frequency (RF) Applications for Wide Bandgap Technology, held April 26 to 27, 2000 at NRL, Washington, DC

In addition, during the contractual period, Palisades published a report for a STAR on Optical Interconnect Technology. This STAR was held on May 11 to 12, 1995 at Palisades. As requested by the COTR, copies of all of the STAR reports which have been cleared for public release are included in Appendix A of this report.

2.1.5 Additional Meetings

In addition, Palisades hosted, at its Crystal City, VA facilities, and provided full meeting support (technical and administrative) for the following meetings related to AGED and/or TPED activities and responsibilities:

- Pre-TARA meeting, February 14, 1997
- Frequency Control Pre-TARA Meeting, February 19, 1997
- TARA Dry Run Meeting (at Naval Research Laboratory), February 20 to 21, 1997
- Tri-Service Materials meeting, April 3, 1997

- Working Group A ad hoc subcommittee meetings on Gallium Arsenide (GaAs) Manufacturing Infrastructure, June 18, 1997; July 16, 1997; August 8, 1997; September 9, 1997; and November 19, 1997
- Air Force technical meeting, June 30, 1997
- Advisory Group COTS STAR Planning meeting, August 22, 1997
- TARA Issues meeting, September 4, 1997
- Oversight Committee of the DDR&E Advisory Board on Microwave Power Tubes Research and Development meeting, September 22, 1997 and December 16, 1997
- Ad hoc committee to discuss how to effectively transition promising electronics developments to products for use in DoD weapon systems, December 17, 1997 and January 15, 1998
- Advisory Group Planning Committee: 6 January 1998
- Pre-TARA Preparation Meetings, February 10 to 12, 1998
- Meeting to discuss RF solid state trends, Navy system needs and relationship of Navy RF solid state programs, and plans to those of other services, July 28, 1998
- TPED Radiation Council Oversight Meeting, August 31, 1998
- TARA Dry Run Meetings, February 2, 3 and 4, 1999
- Frequency Control Technology Meeting, September 8, 1999
- Radiation Hardness Meeting, January 11, 2000

2.2 Technical Support and Consulting Services

During the reporting period, Palisades provided a substantial amount of technical and managerial support to the AGED, the TPED, the services, and the Executive Director of the AGED. This support included preparation of or assisting in the preparation of the following (verbal and written) material:

- A report on the U.S. GaAs infrastructure and DoD-sponsored microwave and millimeter-wave frequency technology development.
- An integrated multiyear electronics plan in response to TARA Major Action Item #12.
- A list of DoD's highest priority electron device S&T programs (see Appendix B)
- A description of AGED, its objectives and current tasks. This material was used to brief Dr. Hans Mark, DDR&E; Dr. Donald Daniel, Air Force; Dr. Frank Fernandez, Director, DARPA; Dr. Tim Coffey, Director, Naval Research Laboratory; Dr. John Tangney, OSD; and Dr. Robert Whalin, Director, Army Research Laboratory (see Appendix C).
- A new plan and agenda format for AGED main group meetings
- A summary report of the Defense Science Board (DSB) Task Force Report on the "Investment Strategy for DARPA."
- A summary report of a "Plan to Streamline DoD's Science and Technology, Engineering, and Test and Evaluation Structure."
- A position paper on "Polymer Microelectronics" (for the Executive Director, AGED).
- Documentation for use by the Executive Director of the AGED on how DoD Directive 5000.1 could be changed to better integrate S&T developments and technology maturity achievements into the weapon systems' acquisition process.
- A strawman plan for a "Quality Assessment of DoD Laboratories."

- Terms of Reference for "Assessment of Current DoD Investment Strategy and Recommended Actions to Assure Transition of Promising R&D Developments to Products and Processes Of Use in DoD Systems."
- Definitions of DoD laboratory "quality" and "relevance" for use by Dr. Hans Mark, DDR&E (see Appendix D).
- Briefing material for the AGED Chairman, AGED Executive Director, and Army AGED Member for briefing Dr. Hans Mark, DDR&E, and Dr. Delores Etter, DDDR&E, prior to the AGED Forum.
- Contributed to briefing material for use by Dr. Mark and Dr. Etter in their presentations to the AGED Forum.
- The post-AGED Forum briefing.
- The AGED Forum report.
- Information and funding profiles for DoD S&T projects on superconducting electronics.
- A narrative, for possible inclusion in a required DoD report to the Congress, identifying technological objectives for R&D that support the achievement of military capabilities, necessary for meeting national security requirements of the next two to three decades. Items submitted for possible inclusion in the report included ones on microwave, microelectronics and electro-optics topics.
- The 1999-2000 AGED Report (Approved by AGED and posted on the AGED web site).
- A chronology of important events in the development of GaAs material devices and Microwave Monolithic Integrated Circuits (MMICs) (prepared at the request of Dr. John Zolper, Office of Naval Research (ONR)).
- TPED Electron Devices Roadmaps (assisted in the preparation and refinement).
- A presentation to the Undersecretary of Defense, Acquisition, Technology and Logistics (USD AT&L) about the projected demand for MMIC-based transmit/receive modules for military active electronically scanned array (AESA) radars and the remaining suppliers of MMICs and MMIC modules for these radars (prepared at the request of the Executive Director of AGED).
- A summary report on the "Key Conference 2000 on Compound Semiconductors in Communications," (prepared at the request of AGED Working Group A).

2.3 The AGED Forum

On August 8 and 9, 2000, the AGED held a forum at The Georgetown University Conference Center in Washington, DC. Its principal objective was to assist the AGED in assessing the impact of the rapidly changing status of the DoD's access to leading-edge electronics technology. It also sought to examine opportunities that are expected to result from 21st century electronics technology advances. In particular, the discussions and presentations at the forum have been used to assist the AGED in its exploration of approaches for effectively investing the DoD's S&T budget to assure that the electron devices, circuits, and components necessary to meet the requirements of the major new DoD initiatives are available and affordable. These initiatives include OSD's S&T Thrusts, the Army's Future Combat Systems program, the Navy's Future Naval Capabilities program and the Air Force's revised air and space programs. The forum was hosted by Dr. Hans Mark, DDR&E, and Chaired by Dr. John Pellegrino, Director of the Army Research Laboratory's Sensors and Electron Devices Division. The keynote speaker was Dr.

Mark. Dr. Delores Etter, Deputy DDR&E spoke on OSD's S&T Thrusts. Leaders from DoD and industry provided their insights on the emerging global environment, new DoD warfighting strategies and their implications for DoD electronics S&T, trends in the electronics industry, and services and DoD agency electronics strategies. All AGED groups participated in the forum. Following the presentations, the AGED Groups met independently to consider their findings, conclusions, and recommendations and then collectively to report them to the AGED Chairman and the AGED Executive Director. Subsequently (after the period of performance for this contract), a report about the forum and findings, conclusions, and recommendations was prepared and will be published by the AGED.

Palisades performed the following tasks in support of this Forum:

Prior to the Forum:

Palisades prepared written material for inclusion in the forum brochure, prepared the forum agenda, helped to secure speakers, made all arrangements for the conference center, reserved a block of hotel rooms at the forum site for use by forum attendees, and planned and arranged an evening social event held during the forum. In addition, Palisades assisted in writing the presentation material used for briefing Dr. Mark prior to the forum, and contributed to the briefing material considered for use by Dr. Mark and Dr. Etter as part of their speeches.

During the Forum:

Palisades technical and administrative staff members conducted registration activities, operated projection equipment, took notes of the proceedings of all sessions, prepared and distributed a summary of all of the speakers' presentations, prepared and distributed summaries of remarks made during the working group deliberations, and prepared a preliminary summary of the findings, conclusions, and recommendations.

After the Forum:

Palisades assisted the chairman of the AGED in preparing briefing material used to brief high level DoD/service officials and contributed substantially to writing and editing the forum report.

2.4 Financial Database

Since Fiscal Year (FY) 1995, Palisades has maintained a comprehensive financial database of S&T funding for electronics projects undertaken by the Army, Navy, Air Force, DARPA, BMDO, and other DoD agencies. (Palisades also has a substantial amount of financial data for such projects from years prior to FY 1995, but this data was not provided by the services and DoD agencies in a consistent format. During FY 1994 and FY 1995, Palisades worked with the services and the AGED Executive Director to establish a suitable format for compiling this data. This format has been used since that time with excellent results.) Data is compiled from information supplied by the services and DoD agencies, such as DARPA and DTRA. It is presented on Excel spreadsheets and charts. Separate spreadsheets are maintained for displaying the financial information grouped by technology area (as listed in the TPED Electronics

Taxonomy) and by service or agency. Other spreadsheets and charts are prepared, upon request, that display the data in additional ways to meet the specific needs of the AGED and/or TPED at a given time. The Palisades' financial database also is an important historical record of DoD S&T expenditures on electronics over the years. This database is used extensively during the electronics TARAs. In addition to this formal database, Palisades' personnel also review the (publicly available) President's budget sheets for DoD S&T electronics programs, when they are released in the spring of each year, and carefully monitor Congressional committee reports for information about additions and deletions to the budgets of DoD S&T electronics program including Congressional language that will impact them.

2.5 Technical Article Database

Palisades maintains a database of relevant magazine, journal, and newspaper articles of interest to the AGED. A summary of current articles is prepared prior to each AGED meeting and distributed to the AGED/AGED working group members as part of their meeting information packet provided at each meeting. The summaries are also available on the AGED web site. A sample summary is provided in Appendix E.

2.6 AGED/TPED Web Sites

During the period of performance of this contract, Palisades developed and is maintaining password-protected web sites for both the AGED and the TPED. The AGED web site contains agendas and minutes for the years 1995 through the present time, agendas for upcoming meetings, the AGED Report, AGED STAR reports (including those cleared for public release, those for "Official Use Only," and those in preparation), STAR Terms of Reference, summaries of technical articles discussed at each AGED meeting, summary reports of technical meetings attended by Palisades' technical personnel at the request of the AGED, an AGED calendar and other information of importance to the AGED membership. The TPED web site contains TPED meeting minutes from 1997 to the present, the TPED technology area roadmaps, a TPED calendar and other information of relevance to the TPED membership. The TARA briefing material from both the 1999 TARA and the upcoming TARA is also posted on the TPED web site. The AGED and TPED web sites serve as excellent reference sources of current and archival information about AGED and TPED activities and are heavily used by AGED and TPED members, respectively. In addition, Palisades maintains a public AGED web site that provides the public with information about the AGED and access to AGED generated documents (e.g., STAR reports) that have been cleared for public release.

2.7 Palisades' Facilities

Nearly all AGED and TPED meetings as well as most the AGED STARs are held at Palisades' facility. Palisades is located within the Arlington, VA, Crystal City complex, directly above the Crystal City Underground and within a few hundred yards of the Crystal City Metro (Public Rail Transportation System) station entrance. Palisades is accessible from the Metro station via completely enclosed, well-lighted pedestrian corridors. It is not necessary to go outdoors. Palisades has two fully equipped meeting rooms that can be joined to accommodate up to 65 attendees or separated to provide space for simultaneous smaller meetings. These meeting rooms

are equipped with state-of-the-art projection equipment, microphones and recording equipment, electrical connections on a conference table to remote servers so that meeting attendees can have immediate access to their E-mail and to the World Wide Web and with electrical outlets for powering laptop computers. In addition, Palisades' facilities contain two high-speed copiers, FAX equipment, state-of-the-art computer equipment populated with many of the commonly used software programs, high-speed access to the Internet, and a guest office for use by visiting AGED and TPED meeting attendees. Palisades holds a SECRET facility clearance and all of its personnel involved with AGED and TPED activities are cleared to the SECRET level. It has secure containers that hold material classified at the SECRET level.

Appendix A

STAR Reports

Micro-Opto-Electro-Mechanical Systems (MOEMS)

Commercial Off-The-Shelf Electronic Components

Mixed-Signal Components

Appendix AA

STAR Reports

Micro-Opto-Electro-Mechanical Systems (MOEMS)

REPORT OF
DEPARTMENT OF DEFENSE
ADVISORY GROUP ON ELECTRON DEVICES
WORKING GROUP C (ELECTRO-OPTICS)

SPECIAL TECHNOLOGY AREA REVIEW

ON

MICRO–OPTO–ELECTRO–MECHANICAL–SYSTEMS

(MOEMS)

December 1997

OFFICE OF THE UNDER SECRETARY OF DEFENSE
ACQUISITION AND TECHNOLOGY
WASHINGTON, DC 20301-3140

CLEARED
FOR OPEN PUBLICATION

JANUARY 9, 1998 **4**

DIRECTORATE FOR FREEDOM OF INFORMATION
AND SECURITY REVIEW (OASD-PA)
DEPARTMENT OF DEFENSE

THIS REPORT IS A PRODUCT OF THE DEFENSE ADVISORY GROUP ON ELECTRON DEVICES (AGED). THE AGED IS A FEDERAL ADVISORY COMMITTEE ESTABLISHED TO PROVIDE INDEPENDENT ADVICE TO THE OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING. STATEMENTS, OPINIONS, RECOMMENDATIONS, AND CONCLUSIONS IN THIS REPORT DO NOT NECESSARILY REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF DEFENSE.

Prepared by the AGED Secretariat
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FOREWORD

Periodically, the Advisory Group on Electron Devices (AGED) conducts Special Technology Area Reviews (STARs) to better evaluate the status of an electron device technology or defense application. STARs strive to elicit the applicable military requirements for a particular technology while relating the present technology status to those requirements. The STAR culminates in a report that provides a set of findings and recommendations which the Office of the Secretary of Defense can utilize for strategic planning. Since each electron device technology that falls under AGED's purview resides at a different level of maturity, and thus, varying requirements, the content of each STAR is tailored to extract the appropriate data through preparation of "Terms of Reference."

This STAR report documents the findings from the review and assessment of micro-opto-electro-mechanical-systems (MOEMS) that was held on 28 May 1997, by AGED Working Group C (Electro-Optics) at the Naval Command, Control and Ocean Surveillance Center, San Diego, CA. The goal of the STAR was to assess the overall status of MOEMS technology and to provide recommendations concerning technical direction and resulting Tri-Service cooperative efforts that will be needed to meet the MOEMS needs of future electron device based systems. Presentations were made by a distinguished panel of experts selected from both industry and government. Working Group C members are subject matter experts in electro-optical technology. The group includes representatives from the Army, Navy, Air Force and the Defense Advanced Research Projects Agency as well as consultants from industry and academia.

On behalf of Working Group C, I would like to take this opportunity to express my sincere appreciation to all of the people who took part in this study – listed on the next page – for their valuable contributions. This applies particularly to Dr. Susan Turnbach, ODDR&E/S&E, whose support and encouragement were essential for the successful completion of this effort. I would also like to extend my thanks to Dr. Jane Zucker of Lucent Technologies for conceiving this STAR topic and recommending expert speakers. Dr. Robert Leheny of the Defense Advanced Research Projects Agency, and Dr. Paul Kelley of Tufts University are also thanked and commended for significant contributions to this study. Their expertise and excellent background material helped immensely in the preparation of this report.

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REPORT OF SPECIAL TECHNOLOGY AREA REVIEW (STAR) ON MICRO–OPTO–ELECTRO–MECHANICAL–SYSTEMS (MOEMS)

EXECUTIVE SUMMARY

Few new defense technologies have excited the professional community as much as MEMS. Utilization of the chip making manufacturing infrastructure to create a new class of devices ranging over a wide number of military applications makes a compelling statement. DARPA initiated this activity and has provided the major sponsorship. Now, an outgrowth of this technology into the optical region, micro-opto-electro-mechanical (MOEMS) devices, offers new potential for defense exploitation. This STAR report has assessed the current status of this technology and provides findings and recommendations for use in future defense technology planning. In particular, the STAR revealed that we are at the beginning of an era of technological advancement that could offer revolutionary new optical system concepts. Evaluation of the individual STAR presentations found that:

- MOEMS affords the capability to fabricate a variety of devices.
- MOEMS has significant potential for use in military systems.
- Commercial opportunities exist for MOEMS, particularly in the display arena.
- Existing fabrication lines can be easily adapted for MOEMS production.

Already, one manufacturer has produced a MOEMS product capable of scanning more than 10^6 laser beams and R&D into integration of this technology into lasers and optical switches is proceeding. Integration of a number of optical functions onto a single chip of silicon has been demonstrated. The Services and NASA are closely following these developments and developing projects to extend the application of the basic technology into a number of system applications. For example, fast optical switches for communication channels, laser beam steering and control, spatial light modulators, image aberration correction, and ultra-fine optical element adjustments all seem to be important applications. The definition of systems requirements to utilize MOEMS is a process which is just starting and will accelerate as the specific devices mature.

Based on these findings, the committee believes that this technology presents an opportunity for revolutionary new optical designs which can offer a competitive military advantage. As devices emerge, the committee recommends that export controls must be carefully planned in recognition of both the significant foreign investment in this technology and the necessity to maintain a large industry production base to lower device costs. The constitution of military service representatives to champion this technology and develop system requirements is deemed an essential recommendation of this committee to properly exploit the technological advantage. From this Service team, with the participation and leadership of DARPA, the committee recommends that a coordinated technology roadmap and plan for system insertion be prepared. The committee has agreed to monitor the progression of MOEMS technology, and, at the appropriate time, report this progression in a follow-up STAR.

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW (STAR) ON MICRO–OPTO–ELECTRO–MECHANICAL–SYSTEMS (MOEMS)

INTRODUCTION

Micro-opto-electro-mechanical-systems (MOEMS) are very new, but, have the potential to be broadly utilized in many military systems. During this STAR the major MOEMS sponsor DARPA, the Services, NASA, industry and university representatives convened to discuss and describe their roles in developing this technology. An effort was made to consider all relevant aspects from military requirements and system utilization, through device development and ultimate production by industry. The Working Group then assessed the collected data in accord with the Terms of Reference, detailed in Appendix E of this report, to develop the Findings and Recommendations, the major product of this review.

The inclusion of micro-mechanical components that have the ability to alter the path of a light beam or to modify a light beam has expanded the range of functionality of MEMS. The MEMS-based optical elements or components are usually versions of bulk or physical optics devices. The most common micro-optical elements are those that reflect, diffract or refract light. Micromachines or systems that include optical components are often referred to as optical MEMS (O-MEMS), micro-opto-mechanical systems (MOMS), or micro-opto-electro-mechanical systems (MOEMS). Perhaps MOEMS is the most appropriate and general descriptor of these systems; it conveys the essential ideas about the size and nature of the elements that are integrated to form a system.

There are three primary characteristics that make MOEMS an important technology development: the first is the batch process by which the systems are fabricated; the second is the size of the elements in the systems; and the third, and perhaps most distinctive, is the possibility of endowing the optical elements in the system with precise and controllable motion. Movement of a micro-optical element permits dynamic manipulation of a light beam. This manipulation can involve (amplitude or wavelength) modulation, diffraction, reflection, refraction or simple spatial deflection. Any two or three of these operations can be combined to perform a complex operation on the light beam. The ability to carry out these operations, using miniaturized optical elements, is one of the key attributes that distinguishes MOEMS from classical physical optics.

TECHNOLOGY BACKGROUND

The field of modern optics has been largely concerned with the generation, manipulation, guidance, or detection of light for information processing. The operation that is relevant to micro-opto-electro-mechanical-systems (MOEMS) is the manipulation of light in one, two or three dimensional space. Here, light is defined to be the electromagnetic radiation in the spectral band from about 200 nm to about 15 microns. This boundary definition is important because the wavelength of light that is manipulated or made to interact with micro-optical elements imposes a lower bound on the component size. This lower bound is a consequence of the laws of diffraction. In order to avoid unintentional diffraction effects, the feature sizes of micro-optical elements must be at least ten times larger than the wavelength of light that is intended to interact with the micro-optical element. If diffraction is the desired effect, then this restriction does not apply.

Conventional micromachines are comprised of micrometer-sized electrical and mechanical components integrated to form micro-electro-mechanical systems (MEMS). These systems are fabricated using the techniques and materials of microelectronics. The most common techniques are (1) bulk micromachining, (2) wafer-to-wafer bonding, (3) surface micromachining, and, (4) high-aspect ratio micromachining. In bulk micromachining, a wet chemical etchant whose etching characteristics depend on the crystallographic surface chemistry of the substrate is used to selectively remove material from unmasked areas to define the geometry of the desired features. Wet chemical etching of this kind is generally anisotropic and a limited set of geometric features can be constructed in this way. To overcome this limitation, wafer-to-wafer bonding is used in conjunction with bulk micromachining to fuse together separately micromachined bulk wafers and achieve the desired geometric features. For further versatility in feature construction, surface micromachining is used. In this method, one starts with a substrate material which serves as a working surface. Multiple structural and sacrificial layers are deposited on it and then portions are selectively removed using a sequence of masking and etching steps. The etching is generally done using reactive ion etching—an isotropic etching process which is independent of the crystallographic surface. To fabricate thick (hundreds of microns to centimeters), high-aspect ratio structures, one uses deep UV lithography, in conjunction with reactive ion etching. In some cases, X-ray radiation from a synchrotron generator may also be used as the source for the lithography. Figures 1(a) and 1(b) show illustrations of two of the most commonly used methods for constructing micromachine features.

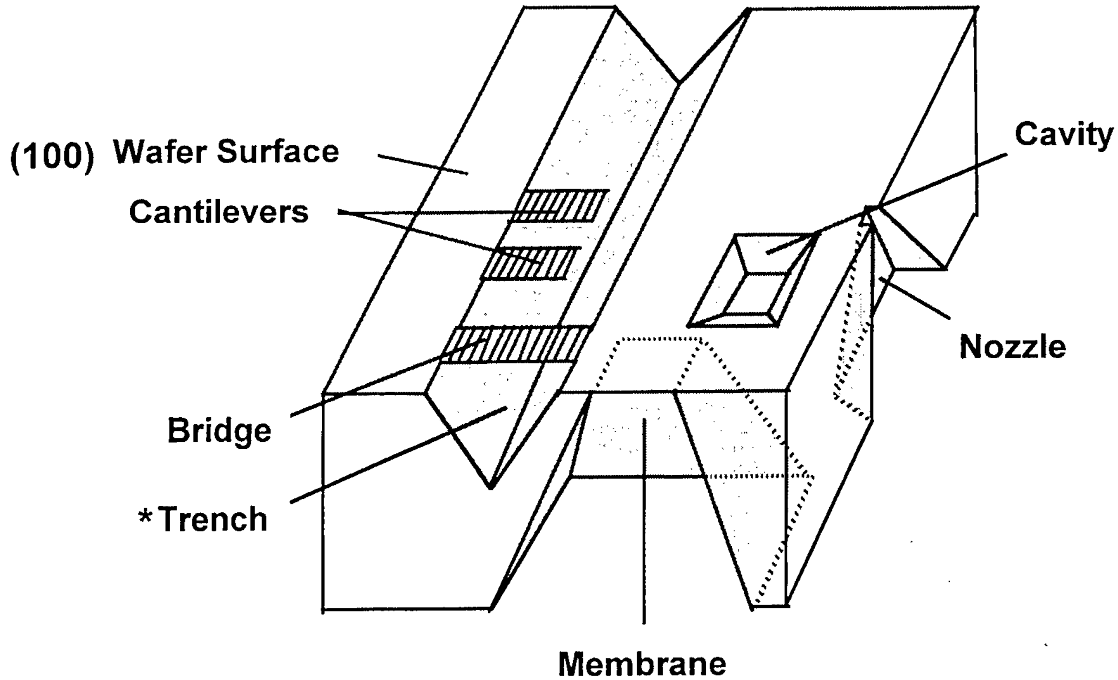


Figure 1(a): An arbitrary component with a composite of all common features and mechanical structures that can be etched in a piece of single-crystal silicon using bulk micromachining. Note that all etched walls are at the same angle as defined by the crystal orientation of the silicon.
* Trench formed by the intersection of the (111) and (yyy) crystalline surfaces.

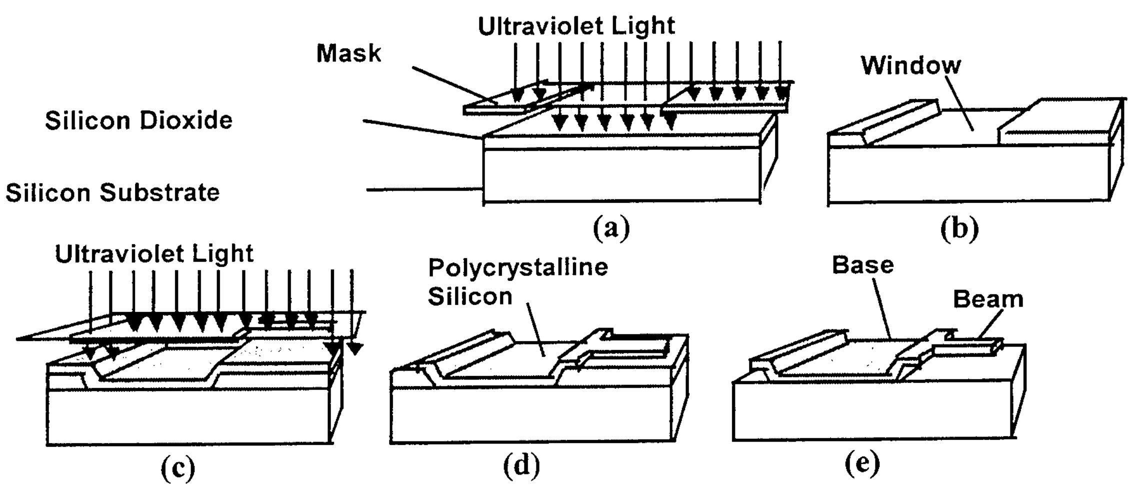


Figure 1(b): A single cycle in a common surface micromachining process. The process to build a single cantilever beam begins with the sacrificial material layer (silicon dioxide) being patterned and etched (a, b). Next, the structural material (polysilicon) is deposited over the entire surface. The polysilicon is then patterned and etched in the shape of the cantilever beam and base (c, d). Finally, the polysilicon is released by removing the remaining and underlying silicon dioxide (e).

The processes described above have been extended to the construction of optical and fluidic components in both silicon and other substrate materials. The generality of the fabrication processes allows one to construct MEMS machines with a diversity of functionality. This functionality can be a result of a distinct class of features or a combination of classes. The major classes of features are:

- Micro-mechanics
  - ◊ replacement of passive lumped electrical elements with surface micromachined equivalents
  - ◊ micro-actuatable membranes
  - ◊ elements with micro-mechanical linear or rotary motion
- Micro-optics
  - ◊ diffractive, refractive and reflective micro-optical elements (fixed or movable) e.g., lenses, gratings, mirrors
  - ◊ micro-optical elements that exploit the free-space properties of light
  - ◊ self-aligned micro-optical elements
- Micro-fluidics
  - ◊ microchannels for fluid transport, storage, separation and reaction
  - ◊ micro-actuated valves for fluid control
  - ◊ micro-pumps for fluid movement

Each class of features can, and often does, include electronic devices that give the microsystem intelligence for control.

In any micromachine, the components of the integrated system, numbering from a few to millions, have dimensions that are measured in micrometers. The fabrication processes described above bring the advantages of miniaturization, multiplicity and diversity of components to the design and construction of mixed technology integrated systems.

GOVERNMENT/SERVICE PRESENTATION SUMMARIES

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY'S (DARPA) MICRO-OPTO-ELECTRO-MECHANICAL MACHINE

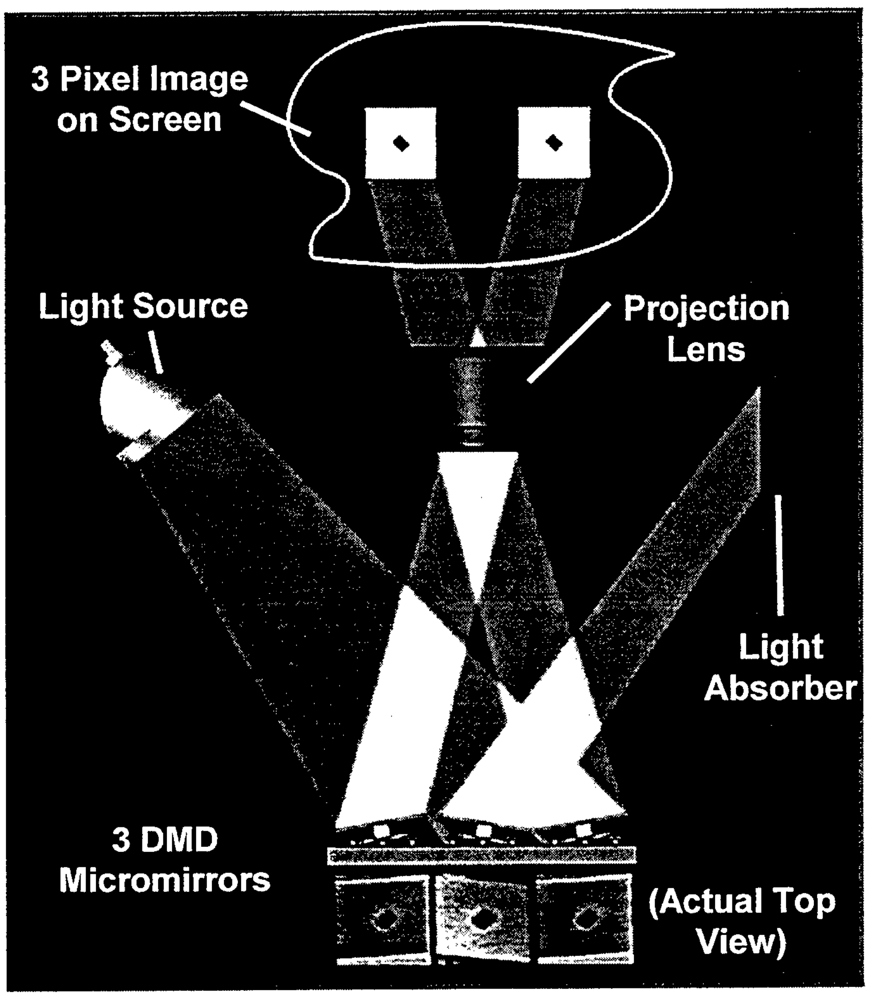
The Electronics Technology Office of DARPA has been involved in supporting research efforts in most areas of MEMS. Recently, the management of the research efforts has been restructured into three distinct areas. These are (1) the traditional MEMS program, (2) the microfluidic molecular systems program and, (3) the micro-opto-electro-mechanical systems area. This last area is currently not a separate program with its own budget; it is part of the traditional MEMS program, differentiated from it by the major role played by micro-optical components in the systems being developed. The emphasis of the microfluidic molecular systems program is on providing the capability to perform tailored, molecular-level chemical and biological reaction/analysis sequences in microsystems. The overall goal of all three areas is to integrate transducers that merge mechanical, optical, acoustic and fluidic elements with electronics to create microsystems that can sense, commute, act and communicate.

One particularly successful early DARPA MOEMS project has been the development and commercialization by Texas Instruments, Inc. of a MEMS based Digital-Micromirror-Display (DMD) Engine incorporating more than a million micro-mechanical components to realize a compact, high resolution, high brightness, projection display module. The DMD Engine represents the largest scale MEMS device undertaken to date as shown on the MEMS roadmap in Figure 5 (see page 11). Figure 2 illustrates the operation of the DMD. The basic structures of the DMD are illustrated in Figures 3(a) and 3(b). Figure 3(a) illustrates the complex micromechanical assembly of a single DMD light switch, while Figure 3(b) is an SEM photomicrograph of DMD chips with one mirror surface removed to exposed the underlying electromechnical structure.

The DMD is an exciting and promising development in the area of truly digital displays using MicroElectroMechanicalSystems (MEMS) technology. The DMD engine holds promise for use in many other applications. It is currently used in high-brightness projection displays. DARPA recognizes the broader applicability of the Digital Light Processing concept and the potential the DMD engine has for both future product innovation beyond the plans of TI and as a stimulating educational tool. To encourage broader application of the DMD engine, DARPA has sponsored a program to explore additional uses of the DMD by making these devices available to the research community. The following DARPA Awards were made for the development of innovative applications that use the Digital-Micromirror-Display (DMD) Engine.

- A New Technique for Adaptive Optics Compensation Using Digital Mirror Devices (DMDs) .... Boston University
- Integrated Modular Holographic Memory .... California Institute of Technology
- Holographic Search Engine for Multimedia Databases .... Colorado State University
- The DMD-ICCD: Use of DMD Technology to Control Optical Interference in Night Vision Systems .... InterScience, Inc.
- DMD Assisted Intelligent Manufacturing of Mesoscopic Devices .... SRI International
- Dynamically Configurable Confocal Microspcopy Using the DMD Engine .... University of California San Diego

Digital Light Processing (DLP) Concept



Texas Instruments

Figure 2

DMD Light Switches

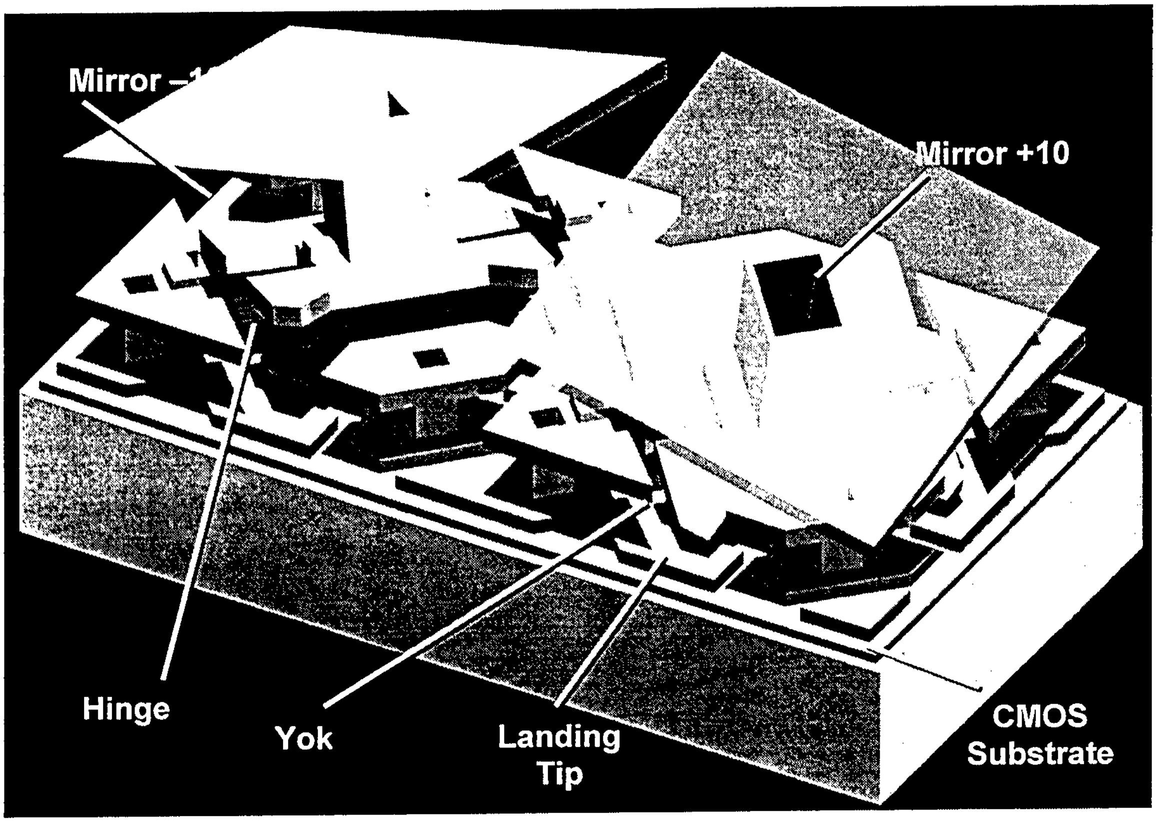
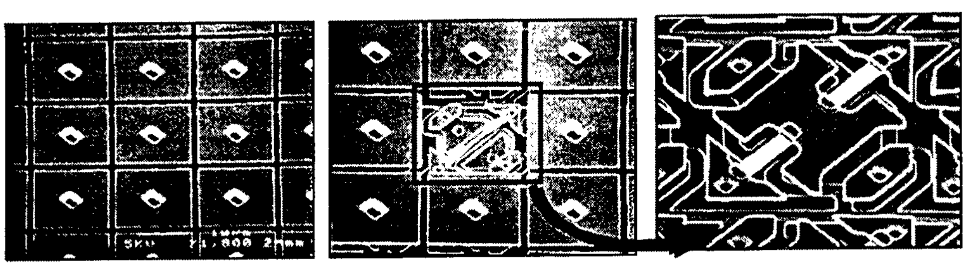


Figure 3(a)



SEM Photomicrographs of DMD Chips

Texas Instruments

Figure 3(b)

One of the goals of the MEMS program at DARPA has been to support and catalyze the development of a technology infrastructure in the United States. To foster this, the Electronics Technology Office helped create and support the Multi-User MEMS Projects (MUMPs) program at the Microelectronics Center of North Carolina (Figure 4). This program has enabled users who do not have access to microelectronics processing facilities to participate in the development of MEMS technology. Since its inception in 1992, over 550 projects from 1000 users have been completed through this program. In addition Sandia National Laboratories has developed a MEMS process based on CMOS processing which they refer to as their SUMMIT process. Air Force researchers (see the Air Force section of this report beginning on page 13) have made extensive use of this process for MOEMS devices. Based on this experience with both processing approaches, the Air Force researchers have found the Sandia multi-layer process has features not found in other approaches such as; a polished upper surface, one-micron design rules, multi layer capability which permits masking any wiring or flexures completely under the polished final optical surface layer. The multiple layers allow shielding wiring so that the optical surface can be metalized after the release etch. Also, an optical surface of choice can be deposited after etching without the necessity of concern about surface integrity after this harsh processing step.

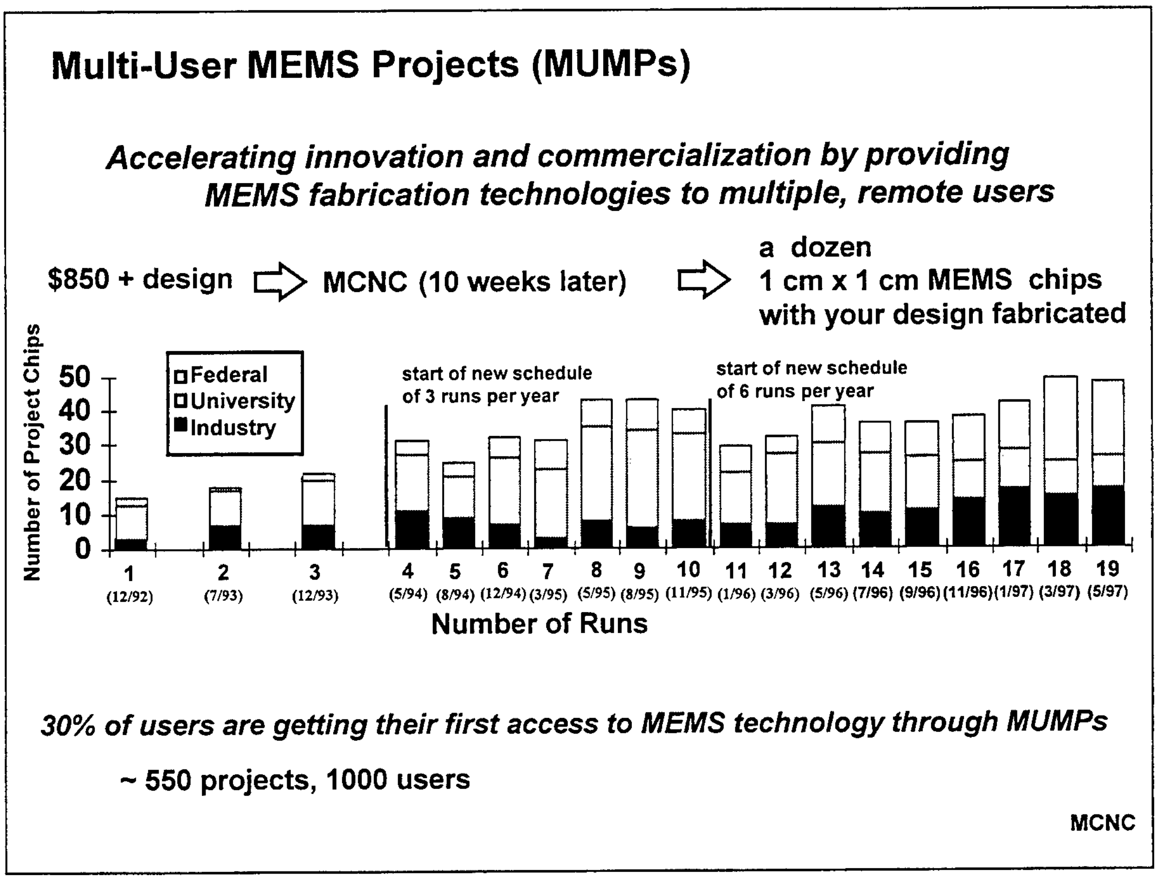


Figure 4

The trend in MEMS technology has been toward systems that can both perceive and control the environment they are in. This trend can be graphically depicted by plotting the number of mechanical components that comprise the system, along one axis, and in terms of the number of transistors that give the system the intelligence to control their environment, in another. The log-log graphic (Figure 5) below illustrates this concept of measuring the abilities to sense and act on the one hand, and the ability to compute, on the other. It can be noted that the mature Digital Mirror Device indicated on the chart offers the capability to scan more than 10^6 laser beams and demonstrates a very high level of integration product.

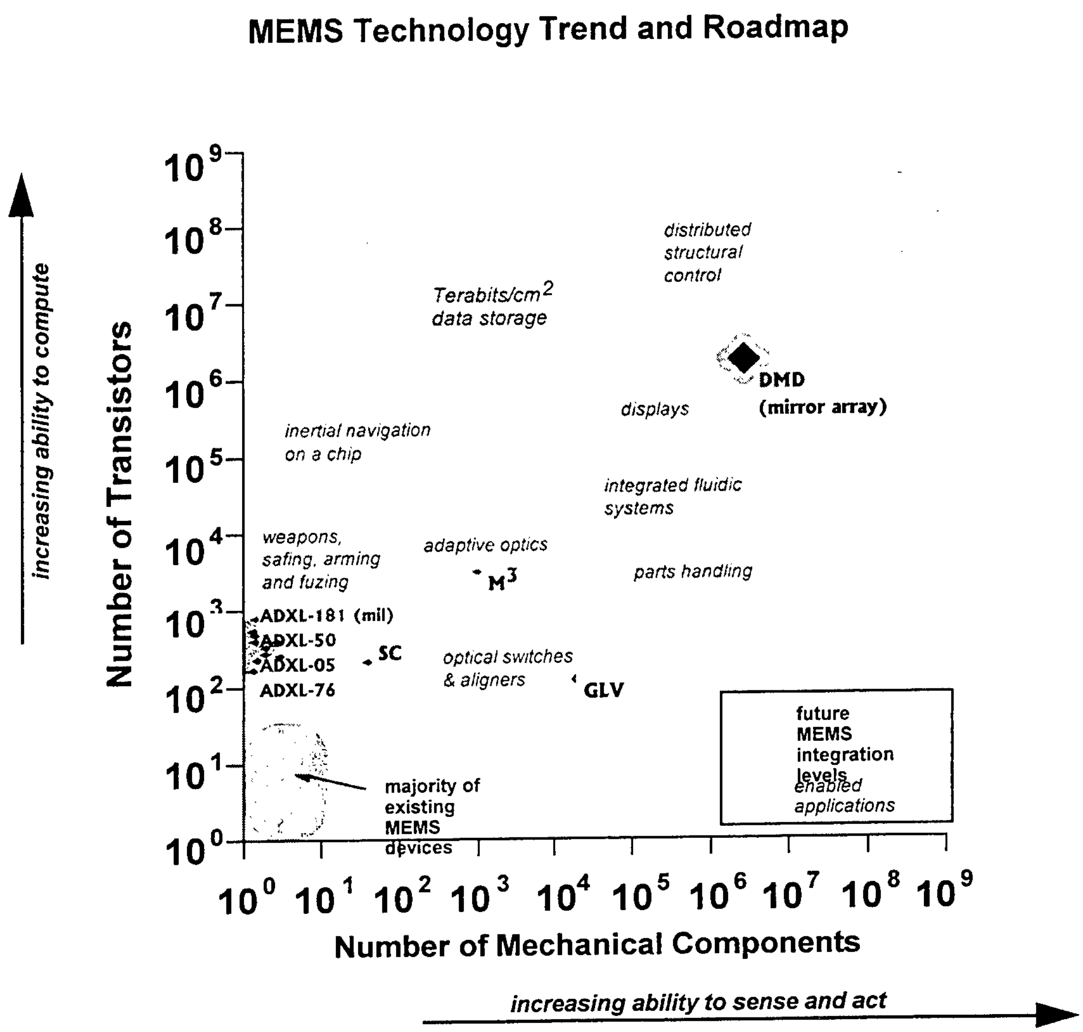


Figure 5

MEMS in general, and MOEMS in particular, have many potential insertion points in both commercial and military sectors. In the military sector, defense applications include (see: *Microelectromechanical Systems A DoD Dual Use Technology Industrial Assessment,* Final Report, December 1995):

- Active, conformable surfaces for adaptive optics.
- Integrated micro-optomechanical components for identify-friend-or-foe systems, displays and fiber-optic switches/modulators
- Mass data storage devices and systems for storage densities of terabytes per square centimeter
- Inertial navigation units on a chip for munitions guidance and personal navigation
- Distributed unattended sensors for asset tracking, border patrol, environmental monitoring, surveillance, and process control
- Integrated fluidic systems for miniature analytical instruments, hydraulic and pneumatic systems, propellant and combustion control
- Weapons safing, arming and fusing to replace current warhead systems and improve safety and reliability
- Embedded sensors and actuators for condition-based maintenance of machines and vehicles, on-demand amplified structural strength in lower-weight weapons systems/platforms and disaster-resistant buildings
- Active conformable surfaces for distributed aerodynamic control of aircraft and precision parts and material handling

Recognizing the potential for insertion of these devices in military systems, DARPA plans to maintain an on-going vigorous activity as can be noted by the sponsorship of projects reported in this STAR.

DARPA's total FY97 funding for MOEMS related research is in excess of $32.5M, including more than $783K in investments in multiple contracts related to DMD Engine applications. More details on the DARPA MEMS program can be found on the DARPA-ETO Web page at the following URL: http://www.darpa.mil.

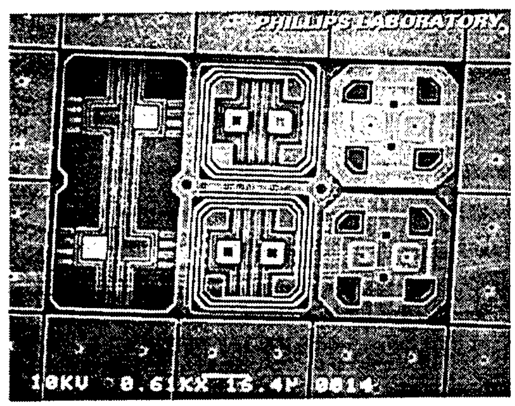
AIR FORCE PROGRAM

Among the services, the Air Force appears to have the most extensive experience with optical applications of MEMS technology. This is the result of the involvement of a small group of individuals at the Air Force Academy and Air Force Institute of Technology (AFIT) almost from the beginning of the emergence of MEMS. In particular, these researchers have had extensive experience working with both the DARPA MUMPs Foundry program and Sandia National Laboratories' CMOS based SUMMIT process for fabricating MEMS devices. Figure 6 illustrates a test mirror array developed at Phillips Laboratory, using the Sandia process. This 64 element array functions as a deformable mirror. It is used for the correction of atmospheric optical aberrations in imaging systems. Figure 7 illustrates the improved image obtained using such a 64 element MOEMS mirror array.

Flexure-Beam Micromirror Device

The FBMD is a phase-only device which deflects its reflective surface along an axis orthogonal to the array. Its characteristic behavior is easily derived from beam theory and electrostatics.

- Poly-0 address wiring runs beneath the arrayed devices
- Poly-1 flexures and shielding which protects wiring from shorting during post-process metallization
- Poly-2 address electrode
- Poly-3 planarized mirror surface



This device is 50μm square and deflects to 320nm at a potential of approximately 7 volts.

Figure 6

Phillips Laboratory researchers are currently pursuing development of micromirror arrays for aberration correction. The objective is to produce a "Silicon Eye" combining state-of-the-art micromirror arrays fabricated at Sandia with a Phillips-patented optics processor which solves partial differential equations encountered in optical processing. This analog processor promises

high throughput and direct analog control of the micromirror positions. The goal is a system which can be digitally controlled to adapt to changing missions, and which also can adapt to changes in itself, caused by radiation degradation, optics degradation, or shock damage. This adaptability to internal or external aberrations will hopefully allow the use of more cost effective optics. In addition, the system should be tolerant of misalignment, reducing the precision needed in the manufacturing and final adjustment of the optics.

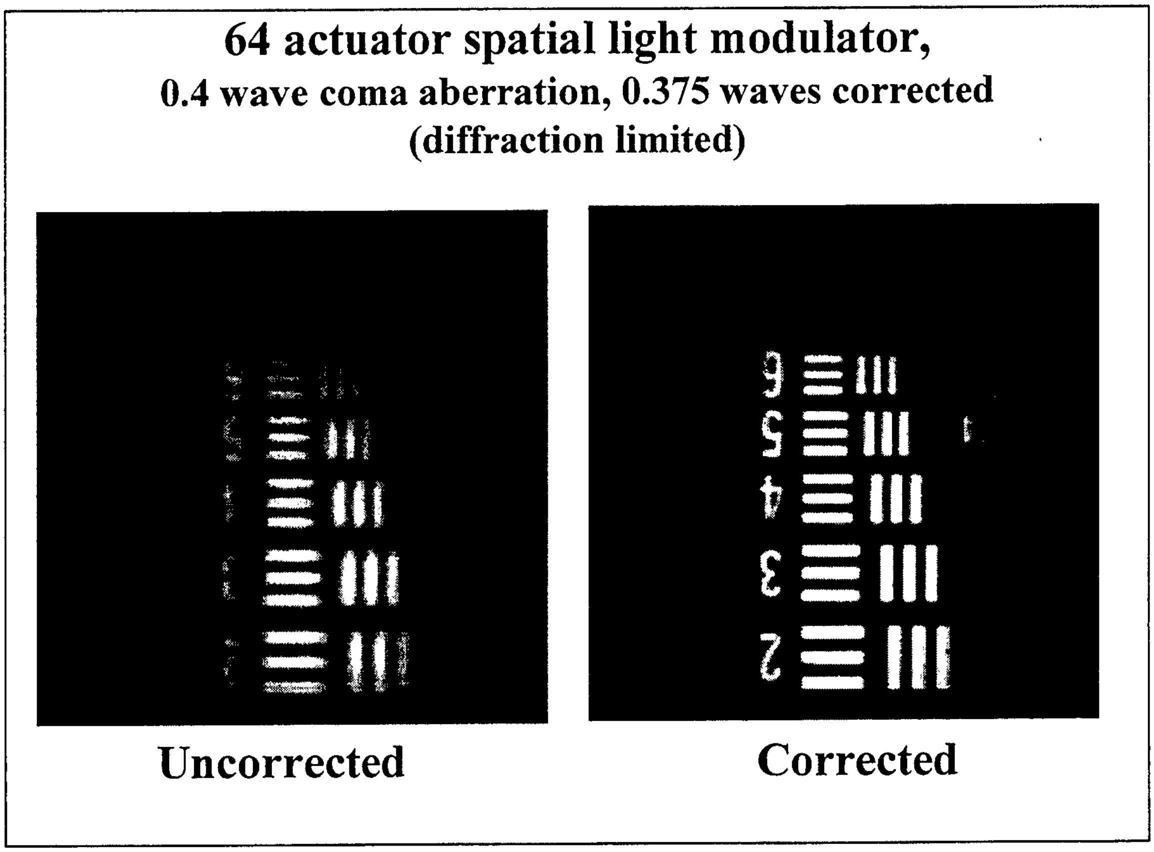


Figure 7

In other work, Phillips' researchers have designed various 2-D tilt/piston-driven mirrors for more sophisticated beam steering and phase control. They also continue to develop thermal actuation and microstepper motors for the assembly and positioning of microoptical components, on, for example, a micro-optical bench. The Phillips approach yields motors with a low-voltage (5-10V) requirement compared to alternative MEMS electrostatic and "scratch" motors which use voltages well in excess of what common CMOS circuitry can provide (upwards of 50V). For this work they will also be exploring use of Sandia's combined micromechanical/electronics fabrication process. DARPA is currently funding a transfer of this process to Analog Devices, Inc., providing a direct manufacturing path for systems developed in this technology.

Preliminary studies on the radiation hardness of micromirror components have begun. Specifically, testing is in progress of the effects of exposure to radiation on micromirror flexures, the most sensitive part of a micromirror, and one for which accurate models exist. This ground based characterization will be followed by space experimentation, to compare device performance in an actual space environment against predicted modeling and ground test results.

Phillips' also sponsors many of the current AFIT research efforts, including work on spatial light modulators, mirror/array characterization, tilting mirrors/variable blaze gratings, beam steering, tracking mirrors, modeling and control of thermal actuators, and MCM packaging of MEMS with control electronics. Past AFIT efforts include: phase control for edge-emitting diode laser beam combining, optical switches including scanning mirrors, and self-assembly of microoptical structures.

At Wright Laboratory, researchers have pursued micro-optics for avionics applications for a number of years. Initial work investigated the use of piston micro-mirror arrays for beam shaping in laser communications systems. As part of this investigation AFIT was sponsored to perform a variety of mirror characterization experiments leading to the understanding of how the arrays functioned as phase and amplitude modulators. More recently, Wright Laboratory researchers have begun investigations aimed at laser beam steering and shaping for laser radar (LADAR) applications. One effort is concentrating on aircraft-based LADAR, and another effort on LADAR for munitions seekers. Models for micro-mirror arrays have been developed and used to estimate expected steering efficiencies. Results of these analyses have been relayed to AFIT, which is being sponsored to design, fabricate, and test mirror array concepts.

The Air Force Office of Scientific Research (AFOSR) is also sponsoring AFIT and other 6.1 research on continuous mirrors for aberration correction.

The present Air Force funding profile for MOEMS is as follows:

• Wright-Patterson AFB	50K/year	97, 98, 99	In-house funds
• AFOSR	115K/year	97, 98, 99	In-house funds
• Kirtland AFB	120K/year	97, 98	In-house funds
and Phase II SBIR	750K/2 years	97, 98	DARPA funds

Some of the issues which must be considered when creating working micro-optical systems identified by the Air Force researchers include: mirror quality, fill factor (optical efficiency), flatness, uniformity of response, mirror coating process compatibility, diffraction from multiple mirror edges, and power handling of micromirror arrays. Also potential bottlenecks in packaging, particularly for large arrays which require many connections, may stimulate research on integration of the mirrors' mechanical devices with their drive and control electronics. Eventually an integrated process that allows integration of all components constituting the entire system on one die—sensors, processing, drive and the mirror themselves may emerge.

Note: For additional information see Appendices A and B.

ARMY PROGRAM

The Army's interest in MOEMS technology arises as part of an overall strategy for success in the information age through improved battlefield situational awareness. ARL researchers have identified (Figure 8) how MEMS based microsensors can help in meeting the Army's advanced technology objectives for individual soldier condition monitoring, distributed sensing for small unit operations, micro-robots, and meso-scale integration. MOEMS are one component of an array of "micro-capabilities" that include micro-actuators, micro-sensors (including optical sensing of micro-cantilever based mechanical and RF probes), and micro photonic devices. The integration of these capabilities is expected to provide enhanced detection of acoustic, mm-wave, microwave, photonics and bio/chemical signals, imaging and unique types of signal processing, on-chip optical processing, information processing and displays and provide affordable, near perfect detection, and rapid, precise discrimination and targeting of all threats in all environments.

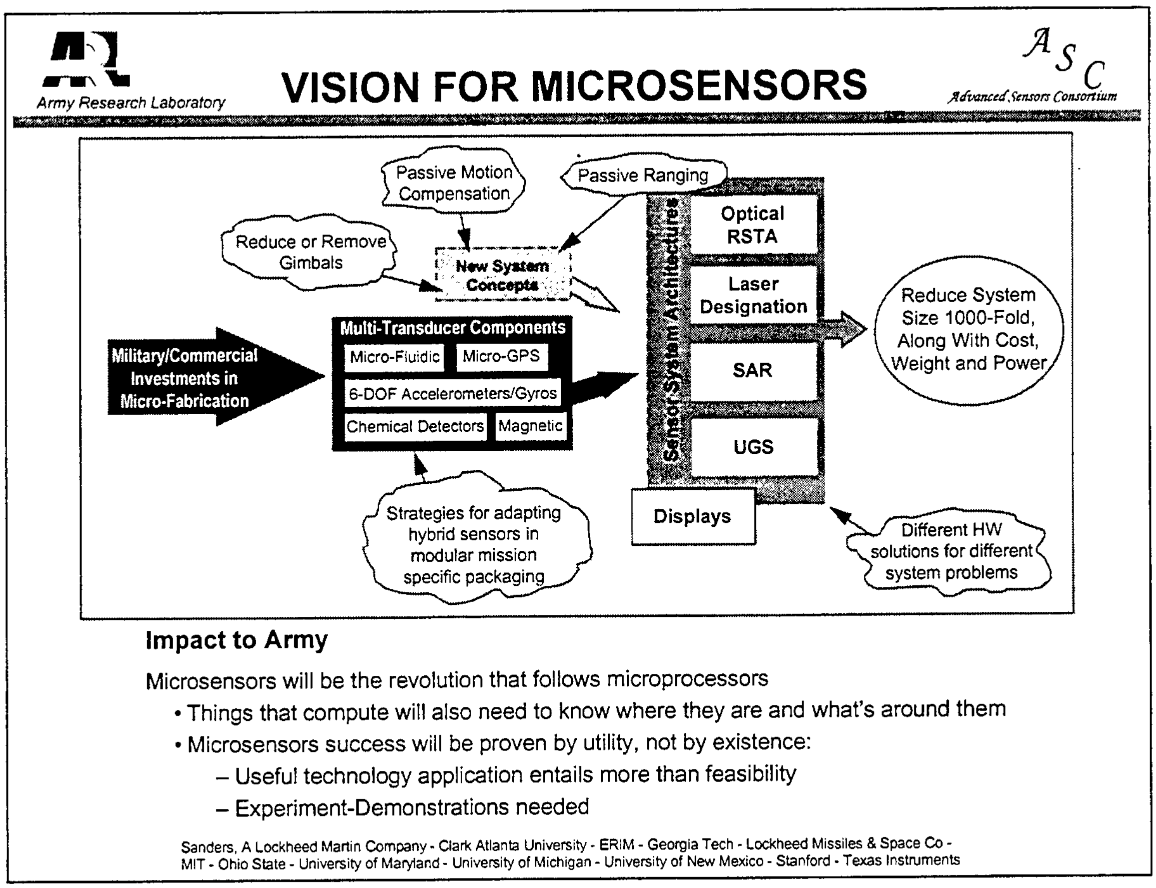


Figure 8

The Army MOEMS development is part of a micro-sensors program for realizing miniature optical, mechanical and electrical components to reduce the size, cost, and power of sensor system architectures. Army philosophy is to augment commercial investments in micro-fabrication with military specific research efforts to provide solutions to various system problems. These solutions will be developed by integrating hybrid sensors into modular, mission specific packages. This type of mixed technology integration will enable new systems capabilities through higher connectivity and higher performance. The long term goal is to provide the Army with affordable micro-sensors that can be widely distributed and interconnected from the soldier to larger scale platforms.

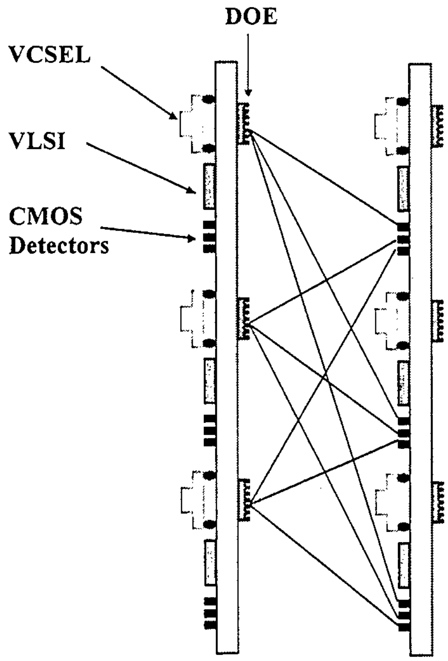
One specific area where MOEMS can have significant impact is in surveillance and reconnaissance requiring the acquisition and processing of visible, IR and near IR images. For this application, the Army is conducting research on an opto-electronic early vision pre-processor coupled to an adaptive detector array. This combination will enable more robust ATR and reduced need for imager data transmission. For example, the human eye is currently better at acquisition and recognition of hidden targets than automated systems are. An adaptive imager patterned after the human process would be capable of performing variable contrast and variable resolution over a single scene. The adaptive nature of this imager is realized from its construction, which consists of layers of opto-electronic devices interconnected optically. The technological challenge for adaptive imaging is the necessity for massive interconnectivity in a small volume. MOEMS could potentially enhance the performance of these arrays.

The Multi-domain Smart Sensor program at ARL is aimed at developing new ways to combine sensors and sensor processing on the focal plane to achieve performance improvements over second generation FLIRs. The concept is to combine passive imaging in the mid-to-far-IR band through a common aperture surveillance system. The architecture is envisioned to include an active Diffractive Optical Element (DOE) imaging system, vertical cavity surface emitting lasers (VCSELs), and DOE coupling to an off-chip processing unit that incorporates advanced signal processing such as scene based uniformity corrections and local gain and offset control. Figure 9 illustrates a conceptional schematic for this integrated vision-based photonic processor. The micro-mechanical part of this system might include micro-dithering of the image by a lenslet array at the focal plane to achieve sub-pixel resolution.

Full awareness of the battlefield is not complete without the addition of chemical and biological sensing. Chemical and biological weapons can be extremely potent. Perhaps the most frightening aspects of chem/bio agents is their low cost, easily concealed production and ease of delivery. Current research is aimed at developing sensor mechanisms that possess the characteristics of detection sensitivity, specificity, compactness, ruggedness, and low cost.

Magnetic Resonance Force Microscopy (MRFM) has been proposed as a means of obtaining 3-D images of individual biological molecules. MRFM is a technique that uses the magnetic resonance imaging concept of selectively exciting magnetic resonances within a slice of a sample. Magnetic resonance is detected by measuring the oscillating magnetic force acting between spins in a sample and in a nearby magnetic particle. High spatial resolution is achieved as a result of the narrowness of the magnetic resonance spectral response and the large magnetic

Integrated Vision-Based Photonic Processor



- Optics used for through wafer fan-out interconnects and feedback
- VLSI for processing, control, and weighting

Figure 9

field gradient produced by the ferromagnetic particle. ARL is interested in MRFM for a number of applications that are detailed in the Army Tech Base Master Plan. For example, it is hoped that MRFM can be directly applied to the imaging of sub-surface defects and mapping of dopant distributions in semiconductors. If force detection of nuclear magnetic resonance can be made sufficiently sensitive to detect singular nuclear magnetic moments it would allow molecules to be imaged in a chemically specific way with 3-D, sub-Angstrom resolution. Optics may be beneficial as a means of detecting the MRFM signal.

The Army is developing novel ways to combine sensors, computation, and communication components into lightweight, low power, modular packages. Various types of microstructures are being investigated for their application to solution of problems with detection, imaging and image processing, optical interconnects and on-chip optical processing, information processing, and displays. Micro-sensor, micro-optic, micro-actuator, and micro-photonic structures can be integrated into hybrid devices to solve these problems for specific Army needs. However, establishment of low cost, monolithic manufacturing capabilities is essential for achieving the payoff from the R&D investment. Government and industrial partnerships are recognized as the key to the success of MOEMS for use in Army applications.

NAVY PROGRAM

No active MOEMS-specific Navy programs were identified. Presently, NRL is conducting a study for DARPA of the application of optics to MEMS manufacture and the potential uses for MOEMS. Of particular interest is application of deformable mirrors, such as the Texas Instruments optical beam steering engine, to such applications such as eye and sensor protection. NRL is also interested in the effects of radiation on these devices to assess their appropriateness for use in space. In a separate effort, NRL has investigated the use of micro-machined mirrors for tuning solid state lasers using an approach similar to that discussed by Professor Harris of Stanford University at this STAR. This effort provided a small business supplier of micro-cavity, laser-diode-pumped, solid-state lasers with the financial support to develop the technology allowing deflective mirror control of the solid state laser output wavelength. However, the program was terminated before a successful prototype was demonstrated. The approach, particularly for use with diode lasers as discussed by Professor Harris, continues to be of interest to NRL researchers.

Note: See Appendix C for Naval Research Laboratory abstract.

NASA (JPL) PROGRAM

No present JPL activities are focused specifically on MOEMS. However, MOEMS are anticipated to have significant potential for cost effective implementation in a range of missions, particularly for exploration of the planets. For this class of application, incorporation of MOEMS into robotic techniques can offer effective solutions for a variety of problems. Specifically, opto-mechanical system applications important to NASA parallel those discussed by the Air Force. These include beam focusing, reflection, diffraction, interferometry, modulation and switching functions, all of which can be miniaturized by use of MOEMS technology.

Among the applications for which MOEMS are anticipated to enhance functionality are: optical imaging of distant and near objects, including higher resolution interferometric measurements; spectrometry across the UV, visible, and IR spectral ranges; beam steering for optical communications; and, optical navigation.

INDUSTRY/ACADEMIA PRESENTATION SUMMARIES

Non-governmental researchers and technologists were in general agreement on a number of characteristics of MOEMS. These opto-mechanical devices/systems are smaller, faster, more rugged and insensitive to shock, capable of precise alignment and displacement, and consume less power than macro-scale devices. Compatibility with VLSI technology enables mass production at low cost. While many of the current device concepts and demonstrations are impressive, the marriage of the base technologies [optics, semiconductor active devices (both opto-electronic and CMOS-electronics) and actuation/agility through semiconductor based micromachining] through large scale integration should achieve significant gains in functionality and entirely new systems capabilities. MOEMS also have advantages when compared to conventional opto-electronic integrated circuits (OEICs); for example, they are the non-planar 3-D devices that are mechanically adjustable and reconfigurable. Since most current MOEMS are Si based, they need to be hybridized with other material systems, such as GaAs and InP, when fabricating active optical devices. It is reasonable to expect that the two microelectronic approaches to optical systems, OEICs that use waveguiding optical circuits, and MOEMS, will merge.

The most successful MOEMS device from a market perspective has been the Texas Instruments Digital Micromirror Display (DMD). VGA and super-VGA displays have been made which are capable of projecting large area images of high luminance. The DMD consists of a 2-D addressable array of electrically deflectable micromirrors, each about 15 micrometers on a side. They are fabricated in a multilayer stack; the process includes removal of a sacrificial layer so that the mirrors can be deflected by an electric field. Currently, there are 13 companies either manufacturing or developing projection systems using DMD technology.[1] Texas Instruments representatives were unable to attend this STAR to make a presentation on this technology.

SILICON LIGHT MACHINES

Dr. Olav Solgaard presented the Silicon Light Machines' approach to commercial display technology. The grating light valve (GLV) that they have invented and are developing is shown in Figure 10. As with most other MOEMS, this device is implemented in Si. In the array of Si ribbons shown, every other element can be electrically displaced vertically, forming a grating and deflecting the light into the projection system of a display (bright state). When there is no voltage applied to deflect the ribbons, diffraction is absent and the system is in the dark state. The width of the ribbons is 2 μm and the length is in the 40 – 120 μm range. The device is fabricated using seven masking steps. In Figure 11, the switching speed and hysteresis behavior are shown. The fast switching speed indicates that a 1-D array can be used together with a galvanometer system for the other dimension. The hysteresis behavior allows clamp-down operation at low voltages. The GLV technology is a potential competitor with another MOEMS based display, the Texas Instruments DMD device. The DMD device is a 2-D array (640x480 and higher) of individually addressable, electrically deflectable micromirrors.

[1]J. Ouellette, *Industrial Physicist*, pp. 9-12, June 1997.

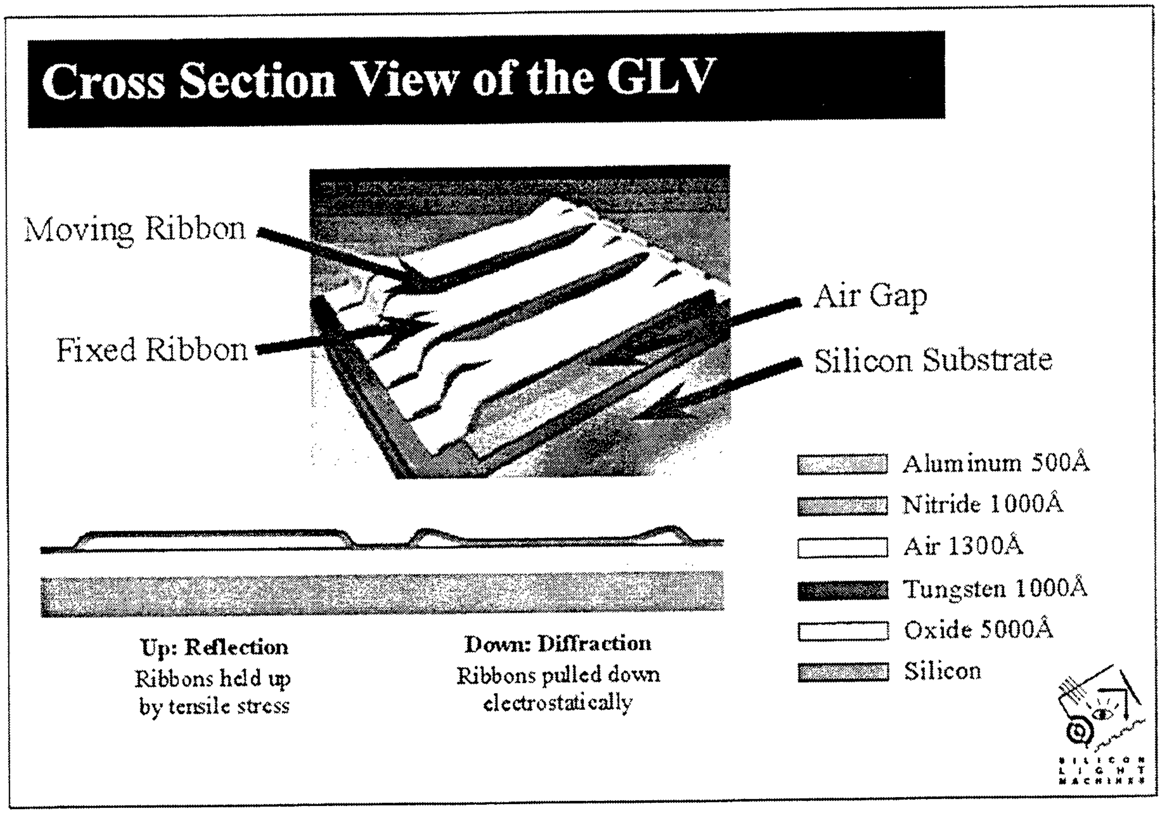


Figure 10

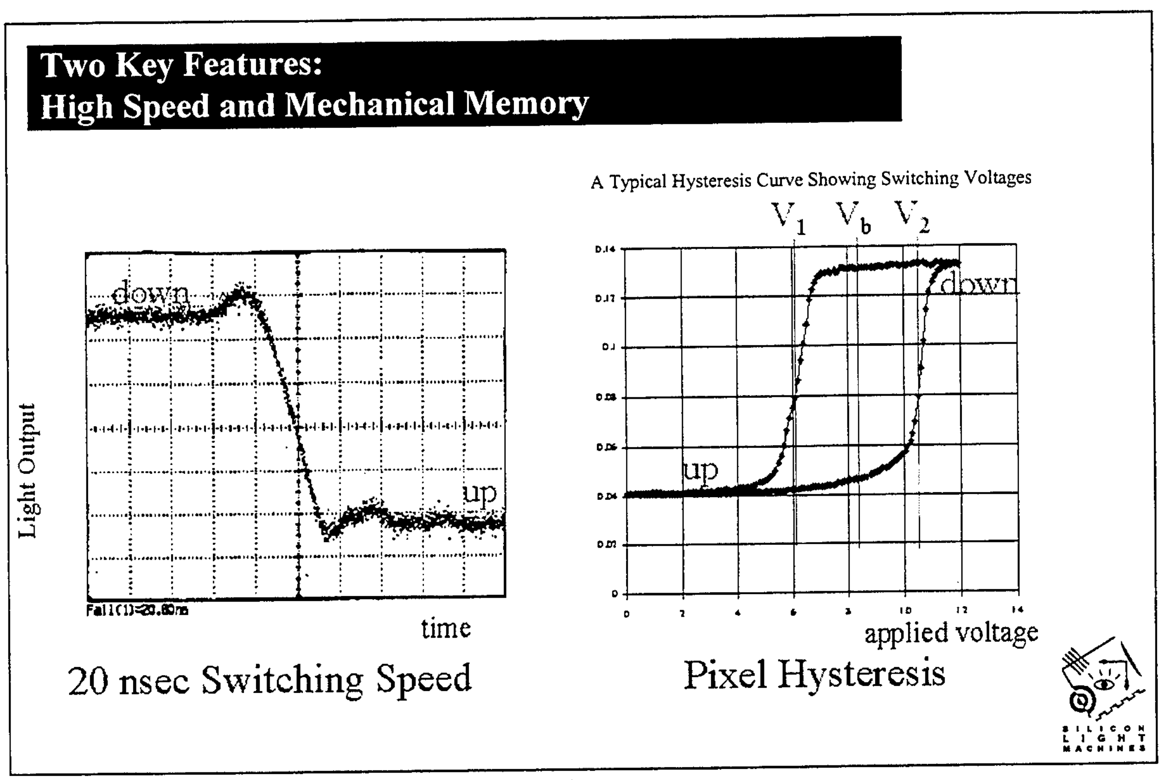


Figure 11

UNIVERSITY OF CALIFORNIA AT LOS ANGELES

Professor Ming Wu of UCLA discussed a number of examples of MOEMS devices such as optical switches, micro-XYZ stages, optical pickup heads, and femtosecond optical autocorrelators. A photograph of the optical pickup head is shown as an electron micrograph in Figure 13. The device uses electrostatic comb drive actuators for adjustment of the pickup. The MOEMS optical disk pickup head can be 1000x lighter than conventional pickup heads which enables faster access time (~ 30x). The micromachined devices are very stable against vibration because of the small inertial masses; individual elements in these devices have high ratios of contact area to volume. Professor Wu gave data on bit error rates for an optical switch, which showed little degradation in performance with a 50g vibration at 150Hz. A self-assembling XYZ stage with integrated microlens, as shown in Figure 12, demonstrates the 3-D character and mechanical adjustment capability of the micromachined devices. The lens shown can be precisely adjusted for XYZ position and pointing accuracy.

NOTE: FIGURES 12 AND 13 PLACEMENT REVERSED DUE TO FORMAT LIMITATIONS

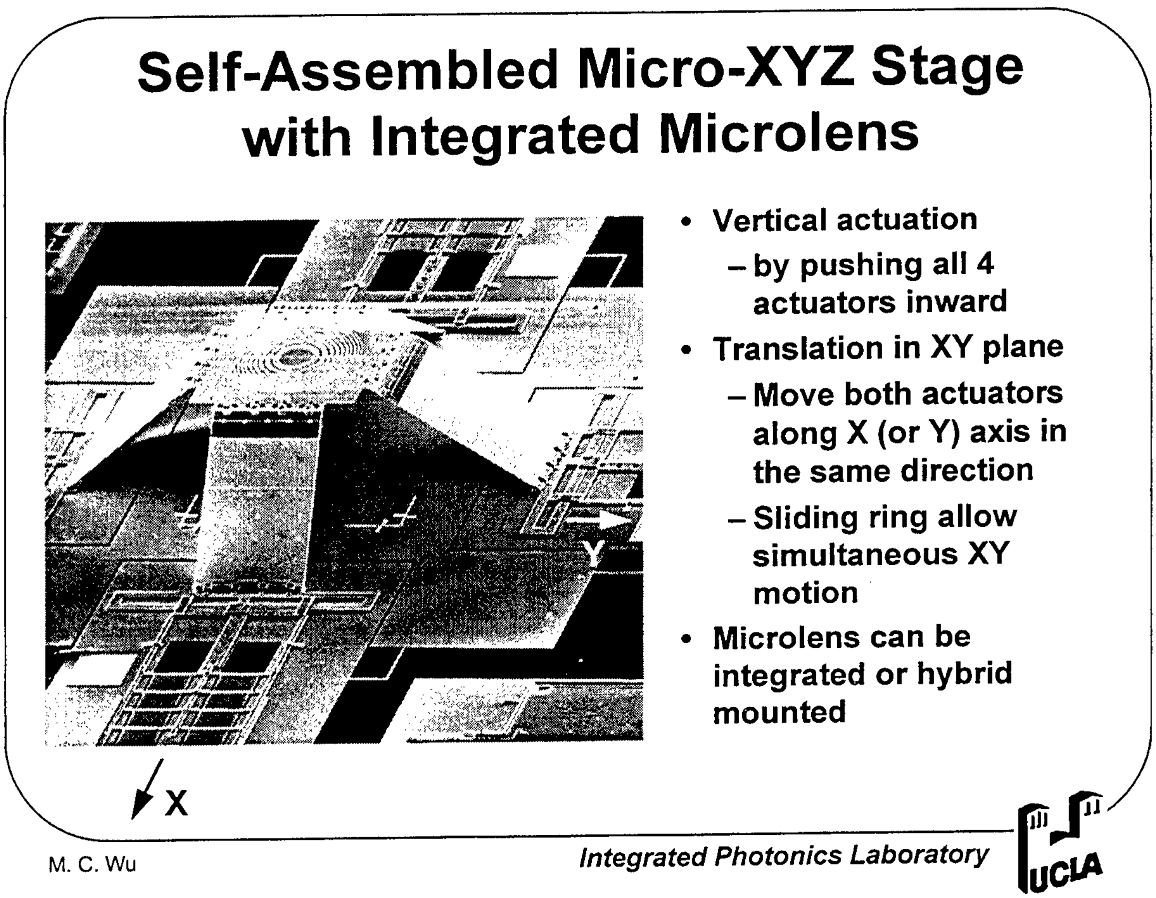
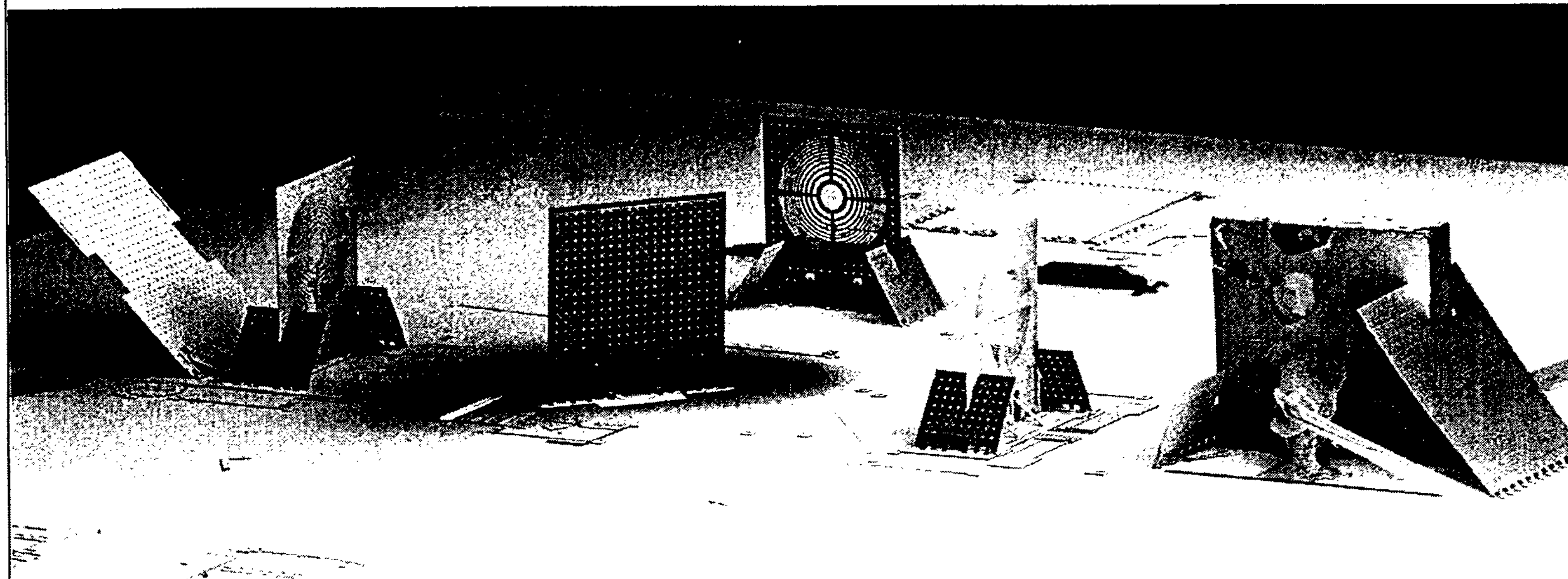


Figure 12

Monolithic Optical Disk Pickup Head



Micro Optics (laser, 3 fresnel lenses, beam splitter, & 45 deg. mirror) Nano-fabrication Micromachining (Fabricated by Ming Wu, L.Y. Lin, J. L. Shen, S. S. Lee, and C. R. King @ U.C.L.A., E.E. Dept.)
50X @ 4"x5" size. (9605-009a)

<u>Free-Space Micro-Optical Bench (FSMOB)</u>

- **Miniaturization**
- **Monolithic integration**
- **Batch fabrication**
- **Optical "pre-alignment"**
- **Integrated microactuators**

- Lin, Shen, Lee, and Wu, Optics Letters, p.155, 1996.
- Picture taken by David Scharf for Scientific American

M. C. Wu

Integrated Photonics Laboratory UCLA

Figure 13

STANFORD UNIVERSITY

Professor James Harris described the research of his group at Stanford on semiconductor diode lasers tuned using a MOEMS structure as one of the cavity mirrors. The mirror membrane structure, which is fabricated over a GaAs/AlGaAs vertical cavity laser, consists of a stress-matched $SiO_2/Si_3N_4/SiO_2$ trilayer and a gold top-layer, the latter serving as one of the cavity mirrors. Electron micrographs of the device are shown in Figure 14, while Figure 15 is a schematic of the structure. Tuning by electrically displacing the cavity mirror gave a response time of 2 μm. In Harris' view MOEMS based tunable lasers, filters, and detectors will be the building blocks for ultra-high capacity fiber and free space WDM optical interconnects, agile reconfigurable interconnects, optical switching, and spectroscopy systems for environmental and battlefield monitoring. Spectra of water vapor taken with the tunable laser are shown in Figure 16.

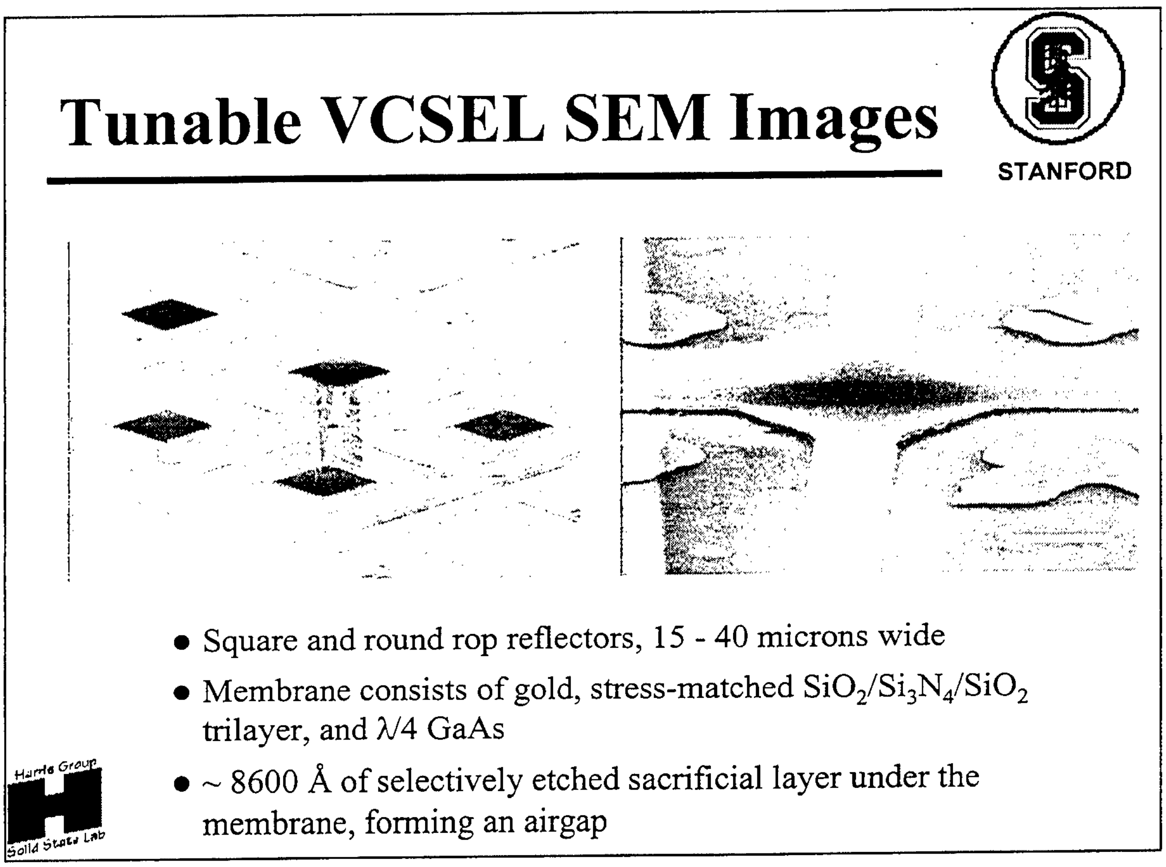


Figure 14

Tunable VCSEL Structure

STANFORD

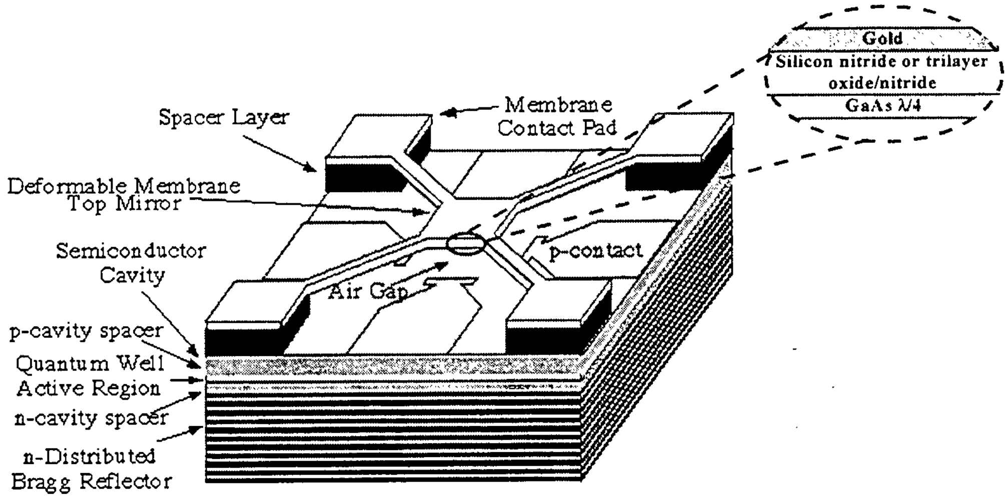
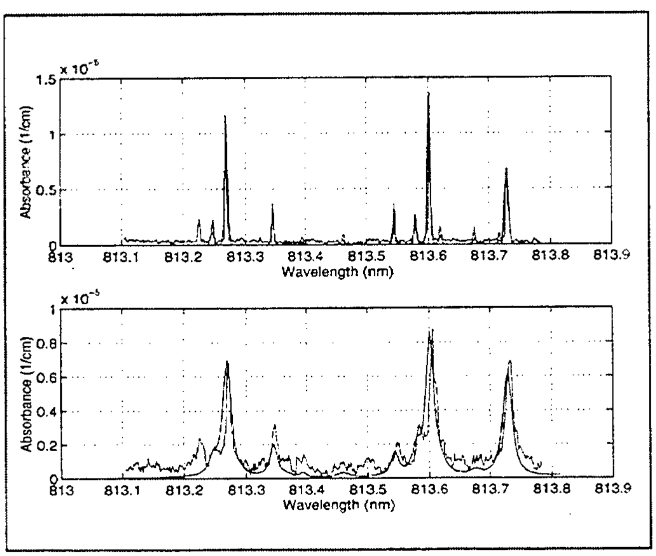


Figure 15

Water Vapor Spectra



- 5 Torr Water Vapor
- Total Pressure: 5 Torr
- Resolution: 180 - 240 MHz
- Scan Step Size: 0.001 nm
- Baseline Noise: 2 x 10^{-8} cm^{-1}
- Sensitivity: 20 ppm

- 60 Torr Water Vapor
- Total Pressure: 1 atm
- Resolution: 240 - 500 MHz
- Scan Step Size: 0.002 nm
- Baseline Noise: 8 x 10^{-8} cm^{-1}
- Sensitivity: 200 ppm

—— Experimental —— HITRAN96

Figure 16

COMMITTEE FINDINGS AND RECOMMENDATIONS

FINDINGS

1. *The innovative aspect of this new MOEMS technology is the capability to combine several mechanical, electrical, and optical functions in a manufacturable "chip" context.*

   Using chip making lithography to define the structures, a variety of devices can be fabricated. A rough categorization of system complexity can be made as a function of degrees and facility of dimensional movement. 1st generation devices feature x, y surface definition with Δ out-of-plane motion over a few optical wavelengths providing, for example, an optical switch via interference. 2nd generation devices feature x, y, z definition with larger mechanical motion possible such as the tunable VCSEL device of Stanford University. 3rd generation x, y, z devices provide definition over extremely large distances, for example, the silicon, erectable optical bench work of UCLA.

2. *At this stage of development of the MOEMS technology, the desirable features and effectiveness for use in military systems, especially laser and sensor systems, can be perceived in generic fashion, but a detailed evaluation has yet to be made.*

   By combining several functions in a technology which seems inherently suited to mass production, MOEMS could offer great cost and performance advantages. This promise must be assessed for individual cases. MOEMS value for performing specific DoD system functions should be compared with that of other emerging technologies.

3. *Current MOEMS device fabrication techniques build on existing chip manufacturing methods. A producible technology capability must evolve, which provides optimization of the key optical parameters.*

   Electrical and mechanical properties have been the focus of MEMS fabrication efforts to date. Key optical parameters like the flatness and low loss in reflection or transmission must be addressed to avoid the performance limitations. Fabrication constraints on, for example, planarization and coatings are important producibility considerations.

4. *There is a large competitive commercial display market which MOEMS can address.*

   The first US company to enter this competitive market is Texas Instruments. It reports success in establishing markets with several licensees for its Digital Mirror Display devices. These are now being produced in a commercial facility.

5. *Generic features of MOEMS have been described which establish this technology as a broadly applicable one with breakthrough potential.*

   These demonstrated features include:

   high mechanical speed ....demonstrated t < 20ns
   high stiction to inertia ratio ....implies stability
   integrated opto-mechanical devices ....adaptive
   small mass ....implies low power and high accuracy

   Other inherent advantages could be enumerated.

6. *Many technical issues remain to be addressed; this technology is still in an infancy stage.*

   With the experience of the integrated circuit industry as a model, several important technical areas and disciplines can be identified as being among those which require additional research and development. These include: packaging, coatings, integrated opto-mechanical CAD design tools, and device models. These technical issues will be addressed in the creation of a MOEMS roadmap.

7. *MOEMS production can exploit the existing integrated circuit manufacturing infrastructure, through suitable adaptation and modification.*

   This could be a real capital investment plus. MOEMS fabrication and production physical plant infrastructure is very similar to that employed by chip manufacturers. As chip making facilities upgrade to accommodate smaller and smaller design features, it seems likely that MOEMS device production could proceed with the addition of special processing equipment on these old excess production lines.

8. *There is vigorous foreign MEMS technology activity as indicated by conference participation and personal contacts. The US appears* to *have a strong MEMS position. MEMS technology is readily translatable to MOEMS technology.*

9. *The export control status of MOEMS is not completely clear.*

   MOEMS are emerging technologies and are not explicitly covered by existing regulations. However, it is clear that:

   - MOEMS "specially developed" for military applications <u>are</u> covered by the United States Munitions List.

- Devices developed for civilian or dual use applications are only covered if the capability they enable is controlled. For example, an adaptive optics controller that allows wavefront correction at closed loop bandwidths above 100Hz is controlled by Section 6.4 of the Commerce Commodities List (CCL), irrespective of how it functions.

- The equipment and technology used to make MOEMS may be controlled by Section 3.B.1 of the CCL, which covers lithography equipment. (The latter section only controls equipment with a source in the EUV below 400nm or where a feature size of less than 0.7 microns can be produced.)

10. *Most MOEMS devices to date have utilized silicon, but other material systems (glass, III-V and II-VI compounds) offer potential important advantages for optical systems.*

RECOMMENDATIONS

1. *The value of MOEMS for use in military system applications should be demonstrated through the following actions:*

    - Each service should identify a technical champion/management team focal point.
    - A service team/DARPA working group should be established to carry out applications definition and other pertinent studies, including identification of R&D transition paths and service budgetary needs.

    The high potential system leverage afforded by MOEMS, even at this early stage of development is the impetus for this recommendation.

2. *As MOEMS R&D projects are conducted a strategy and roadmap should be evolved to implement the required manufacturing infrastructure. This will allow military production to be attained in timely fashion.*

3. *MOEMS may well follow the MEMS course as a global technical activity. The DoD leadership team should be responsive to the need to formulate criteria—protecting military specific developments without hampering commercial activities—for submission to the proper authority establishing export policy.*

CONCLUSION

It should be clear from the foregoing text of this STAR that considerable unfinished business remains in this technical area. To take a positive view, this assessment affords a great opportunity to shape military requirements and technical projects at the outset of a promising new technology. On the negative side, the factual data base regarding the technology potential, applications and ultimate system insertion costs is sparse. The paucity of data and coordinated DoD planning underscores an ongoing need to revisit this STAR and update the findings and recommendations at periodic intervals.

APPENDIX A

AIR FORCE '96 TECHNOLOGY NEEDS FOR MOEMS

Potential Application Areas for MOEMS within the *USAF SPACE & MISSILE COMMAND FY 96 TECHNOLOGY NEED LIST* include:

1. GLOBAL PROMPT STRIKE
   - Autonomous surveillance, tracking, imaging
   - Real time tracking/targeting
   - SBL-multiple - target acquisition, tracking and pointing (ATP) laser development/demonstration (SFA: Full Power Beam Quality)
   - Increased signal collection efficiency of electro-optical (EO) sensors (SFA: High Rate Optical Data)
   - Decreased optical wavefront error for space-based sensors (SFA: Outgoing wavefront Sensing & Measurement)
   - Increased detectivity and/or reduced noise of electro-optical (EO) detection (SFA: Precision Optical Structures)
   - Low cost star sensor

2. SURVEILLANCE AND THREAT WARNING
   - Large, ultra light weight, deployable optics
   - Optical wavefront sensors and correctors

3. ENVIRONMENTAL MONITORING
   - Micromachined earth and sun sensors

4. COUNTERSPACE
   - Adaptive optics for large mirrors
   - Advanced EO weapons threat protection
   - Survivable optics

5. NATIONAL MISSILE DEFENSE
   - Acquisition, tracking, and pointing (ATP)

6. SPACE SURVEILLANCE
   - Autonomous searching, detecting, and tracking by space-based sensors
   - Decreased optical wavefront error for space-based electro-optical (EO) sensors

APPENDIX B

SERVICE POINTS OF CONTACT FOR MOEMS

ARMY

- Ms. Lorna Harrison, Army Research Laboratory, Adelphi, MD (301) 394-3802

NAVY

- Mr. Steven Walker, Naval Research Laboratory, Washington, DC (202) 767-6978

AIR FORCE

- Major John Comtois, PL/VT Kirtland AFB, NM (505) 846-5813
  Spatial light modulators, thermal actuators, steering optics, space systems
- Dr. Lenore McMackin, PL/LI Kirtland AFB, NM (505) 846-2047
  Digital aberration correction, mirror characterization
- Dr. Edward Watson, WL/AA Wright-Patterson AFB, OH (937) 255-9614 ext240
  Beam steering for aircraft laser radar
- Major Jeffrey Grantham, WL/MN Eglin AFB, FL (904) 882-1726
  Beam steering for munitions laser radar
- Major William Arrasmith, AFOSR Washington, DC (202) 767-4907
  Micromirrors for aberration correction
- Dr. Victor Bright, AFIT Wright-Patterson AFB, OH (937) 255-3636 x4598
  MEMS research, micro-optics, design and modeling, thermal mirrors

DARPA

- Dr. Elias Towe (703) 696-0045

APPENDIX C

OPTICS and MEMS

S. J. Walker and D. J. Nagel
Naval Research Laboratory
Washington DC 20375

Optical science and technology have undergone a rebirth during the last three decades, because of lasers and fiber optics. Large new industries resulted. During this same period, integrated circuits have produced the information revolution. In the last decade, the techniques developed for the production of electronic chips have been employed, along with new processes, to produce chips with moving parts. These are called microelectromechanical systems (MEMS). Now, there is an exciting and important confluence of these trends. Optics enable MEMS and optical MEMS to manipulate light and exploit the vast capability of photonic devices.

Optics and MEMS have a natural synergism. On one hand, optical techniques are basic to the manufacturing of MEMS. This is most true of photolithographic patterning methods. However, it increasingly applies to laser direct-write methods for etching or depositing materials during production of MEMS, as well as to the metrology of MEMS during and after manufacturing. On the other hand, a wide variety of MEMS have already been demonstrated to produce, modify or detect optical radiation.

Optical MEMS can be loosely defined as any MEMS device which manipulates light. There is no such thing as a completely optical MEMS, since the second "M" represents "mechanical." Thus we are defining optical MEMS as devices that couple photons and mechanical motion in a meaningful way. Some MEMS devices, which primarily use lasers, waveguides, and photodetectors, test the limits of this definition. Ultimately, these borderline systems will probably include some form of active lens or mirror, and thus will meet the criteria of a true optical MEMS.

Entire optical MEMS with volumes on the order of 1 cm^3 have been demonstrated. Both the small ratio of optical wavelengths to the lateral dimensions of MEMS, and the low energy needed in a MEMS to manipulate light, contribute to the increasing interest and capabilities. The rapid motion of micro-mirrors and other optical elements, which are possible due to the lightweight component parts of MEMS, is also a major beneficial factor. So, too, are the similar physical scales of integrated circuits, fiber-optic diameters, laser diodes, and MEMS.

This review of optics and MEMS begins with a survey of optical techniques used to produce and characterize MEMS. The following section is a detailed treatment of all types of optical MEMS, with emphasis on the few MEMS which are already in commercial production and those devices which show the most promise of being commercial successes. The next section reviews current and projected applications of optical MEMS in a wide variety of research and commercial systems. It is likely that MEMS will be very important in the flat panel display and

optical-fiber communications markets, among others. The concluding section contains remarks on possibilities for the further development and application of optical MEMS, with particular attention to incorporating advanced optical materials in MEMS. An extensive bibliography of the ordinary and patent literature appended.

Selected References:

1. M. E. Motamedi, "Micro-opto-electro-mechanical systems," *Optical Engineering* **33** (11), pp. 3505-3517, (1994).
2. H. Fujita, "Application of micromachining technology to optical devices and systems," *Microelectronic Structures and MEMS for Optical Processing II, Proc. SPIE* **2881**, pp. 2-11, (Oct. 1996).

This abstract is excerpted from NRL Memorandum Report #7975. Copies of this report may be obtained from the authors or the Naval Research Laboratory Technical Information Division at (202) 767-2187

APPENDIX D

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW (STAR) ON MICRO–OPTO–ELECTRO–MECHANICAL–SYSTEMS (MOEMS)

AGENDA
28 May 1997

SPEAKER	AFFILIATION	TOPIC	TIME
Tom Lapuzza	NCCOSC/NRaD	NCCOSC/NRaD Overview	0900-0945
Tom Hartwick	AGED Working Group C	STAR Introduction	0945-1000
Elias Towe	DARPA	DARPA MEMS Program Overview	1000-1030
		BREAK	1030-1045
Olav Solgaard	Silicon Light Machines	Grating Light Valve Displays	1045-1115
Lorna Harrison	Army	ARL Present and Future Needs in Optical MEMS Technology	1115-1130
John Comtois	Air Force	Phillips Laboratory Micromirror Developments	1130-1215
Bob Leheny	DARPA	Review of Morning Presentations	1215-1230
		LUNCH	1230-1330
Bill Tang	NASA JPL	Future Directions in Optical MEMS Technology for Space Applications	1330-1345
Ming Wu	University of California at Los Angeles	UCLA Optical MEMS Program	1345-1415
Jim Harris	Stanford University	Optical MEMS in Tunable Lasers and Detectors	1415-1445
		BREAK	1445-1500
Group Discussion	Speakers & AGED Working Group C		1500-1630
Writing Assignments	AGED Working Group C		

APPENDIX E

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW (STAR) ON MICRO–OPTO–ELECTRO–MECHANICAL–SYSTEMS (MOEMS)

TERMS OF REFERENCE

1. Which technical areas offer the highest leverage for DoD to improve systems and capability? Are there any critical technical issues that should be addressed by DoD?

2. What are the current and future commercial markets for MEMS?

3. Are there specific near-term MEMS applications for DoD systems? If so, when will they be fielded and what is their impact?

4. What DoD funding level is devoted to Optical MEMS? What projects are supported and why? Is the funding adequate and distributed properly? Which areas might be driven by commercial interests? Is the government support for basic research appropriate, given the fact that many other fields are competing for the same funds?

5. Is there competitive pressure from foreign interests? Is there any infrastructure weakness, such as manufacturing processes or a paucity of joint ventures, which would result in an impediment to exploitation of this technology by DoD?

APPENDIX F

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW (STAR) ON MICRO–OPTO–ELECTRO–MECHANICAL–SYSTEMS (MOEMS)

ABBREVIATIONS, ACRONYMS AND DEFINITIONS

AFIT............................Air Force Institute of Technology

AFOSR........................Air Force Office of Scientific Research

AGED ....Advisory Group on Electron Devices

ARL.............................Army Research Laboratory

ATR.............................Automatic Target Recognition

CCL.............................Commerce Commodities List

CMOS ....Complementary Metal Oxide Semiconductor

DARPA.......................Defense Advanced Research Projects Agency

DMD ....Digital Micromirror Display

DoD.............................Department of Defense

DOE ....Diffractive Optical Element

EO ....Electro-Optic(al)

FLIR............................Forward Looking Infrared

GaAs ....Gallium Arsenide

GaAs/AlGaAs ....Gallium Arsenide/Aluminum Gallium Arsenide

GLV ....Grating Light Valve

InP ....Indium Phosphide

IR.................................Infrared

JPL ....(NASA) Jet Propulsion Laboratory

LADAR.......................Laser Radar

MCM...........................Multi-chip Module

MEMS.........................Micro-electro-mechanical-systems

MOEMS......................Micro-opto-electro-mechanical-systems

MOMS ....Micro-opto-mechanical-systems

MRFM ....Magnetic Resonance Force Microscopy

MUMPs.......................Multi-User MEMS Projects

NASA..........................National Aeronautics and Space Administration

NRL.............................Naval Research Laboratory

ODDR&E/S&E..........Office of the Director of Defense Research and Engineering/Sensors and Electronics

OEIC ....Opto-Electronic Integrated Circuit

RF................................Radio Frequency

SBL ....Space Based Laser

Si ....Silicon

$SiO_2/Si_3N_4/SiO_2$ ....Silicon Dioxide/Silicon Nitride/Silicon Dioxide

STARs.........................Special Technology Area Review(s)

USAF ....United States Air Force

VCSEL........................Vertical Cavity Surface Emitting Laser

VLSI............................Very Large Scale Integration

WDM ....Wavelength Division Multiplexing

Appendix AB

STAR Reports

Commercial Off-The-Shelf Electronic Components

REPORT OF
DEPARTMENT OF DEFENSE
ADVISORY GROUP ON ELECTRON DEVICES

SPECIAL TECHNOLOGY AREA REVIEW ON COMMERCIAL OFF-THE-SHELF ELECTRONIC COMPONENTS

June 1999

OFFICE OF THE UNDER SECRETARY OF DEFENSE
ACQUISITION AND TECHNOLOGY
WASHINGTON, DC 20301-3140

CLEARED

FOR OPEN PUBLICATION

JUNE 7, 1999 **3**

DIRECTORATE FOR FREEDOM OF INFORMATION
AND SECURITY REVIEW
DEPARTMENT OF DEFENSE

Prepared by the AGED Secretariat
Palisades Institute for Research Services, Inc.
1745 Jefferson Davis Highway, Suite 500, Arlington, VA 22202

FOREWORD

Periodically, the Advisory Group on Electron Devices (AGED) conducts Special Technology Area Reviews (STARs) to better evaluate the status of an electron device technology for defense applications. STARs strive to elicit the applicable military requirements for a particular technology or approach while relating the present technology status to those requirements. The STAR culminates in a report that provides a set of findings and recommendations which the Office of the Secretary of Defense can utilize for strategic planning. The content of each STAR is tailored to extract the appropriate data through preparation of "Terms of Reference."

This STAR on Commercial-Off-The-Shelf (COTS) electronic components was conducted on 4 and 5 December 1997 at the Naval Research Laboratory, Washington, DC. Its objective was to gather information which would allow the AGED to assist the Department of Defense (DoD) to identify and distinguish between three classes of electronic components for use in DoD systems. These classes of components are: (1) those components which are available as COTS products and can be effectively used without further R&D investment or logistics support, (2) those in which modest DoD R&D investment can extend the performance and/or military robustness (i.e., COTS adapted for military purposes), and (3) those custom electronic and electro-optic ones which have performance or environmental characteristics that will result in clear advantages for DoD warfighting systems compared with those of our potential adversaries. The components in the latter category are ones that may require DoD R&D investment to allow them to meet the performance challenges of DoD systems required by military mission statements. The STAR also sought to examine those factors necessary to create new COTS components, needed by DoD, for availability in the longer term. This report documents the findings of that STAR including a review and assessment of the use and potential use of COTS electronics components in DoD weapon systems.

Presentations were made by a distinguished group of experts from industry, academia and government. The plenary session provided an opportunity to hear the views of Dr. Jacques Gansler, Undersecretary of Defense for Acquisition and Technology; Dr. Richard VanAtta, of the Institute of Defense Analyses; Mr. John Young, a professional staff member of the Senate Appropriations Committee; Mr. John Hartman of the Hughes Aircraft Company who represented the Electronic Industries Association; and Dr. Thomas McGill, a professor at the California Institute of Technology, concerning the use of COTS processes and products in implementing DoD systems. Because of illness, Dr. McGill participated by audio and video hookup from the California Institute of Technology. Following the plenary session, several panels of experts were convened to discuss various aspects of the implementation of COTS technology in DoD systems. This format, used for the first time in an AGED STAR, encouraged maximum interaction between experts on the AGED COTS STAR panels and other participants.

On behalf of the Advisory Group on Electron Devices, I would like to take this opportunity to express my sincere appreciation to all of the people who took part in this study – listed in the following section – for their valuable contributions. This applies particularly to

Dr. Susan Turnbach, ODUSD(S&T)/SS, whose support and encouragement were essential for the successful completion of this effort. I would also like to extend my thanks to Dr. Gerald Borsuk, a member of the COTS STAR Executive Committee, from the Naval Research Laboratory, for proposing this STAR topic and doing so much to assure a successful meeting. In addition, the other members of the COTS STAR Executive Committee, Mr. Robert Bierig, Dr. Barry Dunbridge, Dr. Thomas Hartwick and the Executive Secretary, Mr. Eliot Cohen, are also thanked and commended for significant contributions to this study. Their expertise helped immensely in the preparation of this report.

Dr. William G. Howard, Jr.
Chairman, Advisory Group on Electron Devices

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Executive Summary

The Advisory Group on Electron Devices (AGED) held a Special Technology Area Review (STAR) on the use of Commercial Off-the-Shelf (COTS) electronic components in DoD weapon systems. This STAR was held on December 4 and 5, 1997 at the Naval Research Laboratory in Washington, DC. A large number of distinguished plenary session speakers including Dr. Jacques Gansler, Undersecretary of Defense for Acquisition and Technology, presented their views on this topic. Following is a summary of the major findings and recommendations resulting from this STAR:

KEY FINDINGS AND RECOMMENDATIONS FROM COTS STAR

Findings:

It is recognized that appropriate use of COTS electronics components during development of new systems and system upgrades is essential to reduce costs in order to stay within shrinking acquisition budgets, maintain technology currency as system life cycles shorten and balance the needs for high system performance with acceptable costs. However, it is also unequivocally clear that, although COTS usage will continue to expand, the need for military-unique components to maintain warfighter superiority will not disappear. **There is and will continue to be a need for the DoD to invest in electronics R&D. The benefits of this investment are clear and compelling.**

<u>**Need for Defense Unique Components:**</u>

- **With the continually shrinking market for defense components, it is unlikely that commercial suppliers will develop military unique components without direct funding support and guidance from the DoD.**

- **The following are examples of defense unique components which will require continuing DoD R&D investment in order for the U.S. to maintain military superiority:**

  ⇒ High performance, high frequency, wide bandwidth microwave electronics (2 to 200 GHz)
  ⇒ High bandwidth analog-to-digital converters (0.5 to 20 Gsps)
  ⇒ Devices and components for operation at very high temperatures
  ⇒ Electro-optic IR imaging arrays, EO components for missiles, and related components
  ⇒ UV/IR Detectors
  ⇒ Radiation-hardened integrated circuits for space
  ⇒ High power RF sources - solid-state and vacuum (5 to 100 GHz, 1 to 1000 Watts)
  ⇒ MEMS for miniature UAVs
  ⇒ Electronically steered antenna arrays for multiple agile beam forming
  ⇒ High performance, highly integrated packaging and interconnect MCM technologies

• Without an enhanced continued U.S./DoD S&T investment in these types of military-unique technologies, the military superiority the U.S. has enjoyed in the latter part of the 20th century will gradually disappear in the 21st century, simply because superiority translates to time lead. This 5 to 10 year time lead must be provided by unique technology that is not available to potential U.S. adversaries, and difficult to reverse engineer in a short period of time.

• It is desirable to make use of commercial processes and practices, to the maximum possible extent, to produce needed military-specific electronics parts.

<u>Use of COTS:</u>

• It is desirable to use COTS components to the maximum extent possible when they meet system performance and environmental requirements.

• The balance between COTS exploitation and military-unique electronics technology needs in the 21st century will vary with the type of platform and segment of the weapon system (sensor-processor-network) being built.

• A serious problem encountered with the use of COTS parts is the inability to purchase them as system production progresses because they are discontinued by their manufacturers. This problem often occurs as a result of rapid changes in technology.

• Adequate reliability and durability must be assured when using COTS to meet the requirements for long DoD system lifetimes and to avoid system failure during missions.

Recommendations:

- **A clear U.S. and DoD long-term policy of support for robust military-essential electronics science and technology investment should be established by the DDR&E with Service concurrence by October 1, 1999, traceable to military superiority needs. Responsibility must be assigned within DoD to implement the developed policy, with coordination and contributions from other government agencies (NASA, DoE, DoC).**

- **It is essential that DoD provide sufficient funding to adequately support the development, production and availability of military unique components, needed in DoD systems in order to provide our warfighters with a competitive advantage compared with their adversaries.**

  DoD must continue to make significant and often long-term S&T investments in many electronics technology areas to assure that its competitive military position is maintained – these **investments must include funds to transition successful R&D achievements from proof-of-concept demonstrations to products that are affordable and readily available for use in DoD systems.** A plan for transitioning R&D results to manufacturing should be developed by the DDR&E and implemented by the Services by December 1, 1999.

- **A strategy must be developed for the design and production of dual-use electronic components and processes. By doing so, significant savings and increased efficiency will result as well as improved yield.**

  DoD must innovate and experiment with approaches to leverage commercial processes and production lines to obtain the products it needs at an affordable cost.

- **COTS electronics components should be used, for new systems and system upgrades, when satisfactory levels of performance and reliability can be achieved from them, to reduce costs while meeting needs for high system performance.**

  The scope of parts warranties must be documented in writing by parts manufacturers and clearly understood by DoD system program managers. The organization responsible for meeting warranty obligations and the time period of the warranty must be clearly identified. Parts must not be operated in violation of warranty conditions.

  A decision must be made at the inception of a system design to procure a lifetime supply of required parts or plan for periodic upgrades, making necessary hardware/software upgrades to accommodate new part types or technologies as they become available.

- **DoD should leverage:**
  - ⇒ **commercial fabrication capabilities**
  - ⇒ **commercial system design processes**
  - ⇒ **commercial management and technology development approaches**
  - ⇒ **by dovetailing military development with the full spectrum of commercial development processes**

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW (STAR) ON COMMERCIAL OFF-THE-SHELF (COTS) ELECTRONIC COMPONENTS

Plenary Session

Dr. William G. Howard, AGED chair, opened the plenary session. Dr. Howard reminded the attendees that the DoD was no longer dominant in the development of electronics technology, such as it was during the Minuteman era of the 1960s. He also drew attention to the Revolution in Military Affairs; in recent years, the acquisition budget has shrunk by 60%, we have vastly different enemies than those of the cold war period, and vastly different warfighting scenarios. The use of COTS is an important consideration in efforts to address more diffuse military tasks and requirements with smaller budgets. Dr. Howard stated a number of important issues facing DoD system designers when making their decisions as to which components are acceptable for use in their systems. These include a determination of what is really available, whether or not the part(s) under consideration will operate reliably, consideration of unique packaging requirements to meet system footprints, whether leading edge specifications will be met, if long range logistics considerations will be satisfied and if the selected hardware and software will be compatible with each other. Dr. Howard next introduced Dr. Jacques Gansler, Undersecretary of Defense for Acquisition and Technology.

Dr. Gansler identified two critical acquisition issues facing the Department of Defense in coming years: what it buys and how it is bought. He drew attention to the fact that the United States has deferred modernization during the past decade, with a procurement account that has fallen by more than 70%. He unequivocally stated that we can no longer continue on this path. Equipment is wearing out and becoming obsolete whereas technology has changed dramatically. There are different threats facing us than in the past. These new threats include terrorist actions, transnational actors and rogue nations, and major urban and theater conventional, chemical, biological, and nuclear warfare. These threats must not only be countered, but the U.S. must stay ahead of them. Our decreasing dollar investment must be made to accelerate the pace of modernization. This is unquestionably a difficult challenge. Dr. Gansler also reminded the attendees that it makes no sense, from any standpoint, either to use out-of-date equipment or to spend money updating equipment that is no longer tactically or strategically relevant. The U.S. must fully exploit its leadership in advanced technology and achieve truly integrated, multi-service operations, at all levels; and increasingly, on a multi-national basis.

A recommended approach to cost-effectively meeting DoD technology needs is for the DoD to engage in a greatly expanded partnership with a revived and prospering commercial industry. Civilian/military integration in the acquisition process is the key to the success of such a partnership. A strategy must be developed for the design and production of dual-use electronic components and processes. By doing so, significant savings and increased efficiency will result as well as improved yield. Dr. Gansler cited the MIMIC program as a favorite example of how a dual-use component strategy can be effectively implemented. In this program, criteria of low cost and high reliability were added to the traditional DoD quest for maximum performance. As

military microwave monolithic integrated circuits resulting from the program were deployed in weapons systems, including HARM and GEN-X, commercial circuits were concurrently being put into use, in increasingly larger numbers. These were used by the commercial RF wireless industry for advanced communications and by the auto industry for collision control devices and automated toll collection systems. Thus, the dual-use concept worked with typical chip costs dropping from about $8,000 to approximately $200 and, in some cases, to much lower amounts. Dr. Gansler also cited TRW's production, on its automotive component production line, of military-unique plastic encapsulated circuits and boards for the Air Force's F-22 fighter aircraft and the Army's Comanche helicopter as an example of how to achieve significant cost savings, on the order of 30%-50%, while satisfying DoD needs.

Dr. Gansler drew attention to a recently initiated cost savings program called COSSI – the "Commercial Operations and Support Savings Initiative." This program offers incentives to prime contracts to help the DoD identify commercial parts and services that can be used in its fielded, legacy systems.

Dr. Gansler stated that meeting the DoD needs of the future will require both COTS and some defense-unique systems, subsystems and components. He emphasized that **there is and will continue to be a need for the DoD to invest in electronics R&D and that the benefits of this investment are clear and compelling**. He closed by stating: "I do not see COTS as a process whereby DoD simply buys electronic equipment and components off-the-shelf when it is convenient to do so and when it happens to meet the requirements (or nearly meet the requirements) for the job. We want to see systems and subsystems designed with commercial and military applications in mind and built on integrated production lines wherever possible. Only then can we achieve the most effective use of our limited investment dollars. And only then can we really provide our commercial industry with the resources and incentives to keep ahead of our competitors and our enemies."

The next speaker was Dr. Richard VanAtta of the Institute for Defense Analyses. Dr. VanAtta examined two technology areas of current importance: flat panel displays and semiconductor manufacturing. For flat panel displays, concerns centered upon sustainability of supply, assured supply (since nearly all flat panel displays used by DoD are foreign made), life cycle costs, adequacy of test data, adequacy of qualification procedures, the role of DoD R&D in future display development and application, and the robustness of the U.S. display manufacturing infrastructure. For semiconductor manufacturing, he cited a recent study which concluded that, **to meet DoD microelectronics needs, there must be sustained investment in the semiconductor manufacturing and equipment infrastructure**. Dr. VanAtta commented upon the importance of the DoD proceeding with an effective dual-use strategy to meet its needs. He cited key concerns about COTS, including mismatches between commercial and military product cycles and the likelihood of needing to rapidly ramp-up military technology and industrial capabilities if a war or major conflict occurs. He concluded by stating that **COTS doesn't mean not investing (in electronics R&D) – it means changing the way DoD invests**.

Mr. John Young, a professional staff member of the Senate Appropriations Committee, emphasized the need to focus upon meeting the needs of DoD systems with R&D resources that have been shrinking every year. He noted that contingency operations have taken a toll on RDT&E budgets as well and will probably do so during the coming year. Mr. Young challenged

the DoD to procure more efficiently and less expensively. He commented that use of COTS was part of an appropriate strategy for meeting DoD needs but that adequate reliability and durability must be assured. He also cited DARPA as a leader in adapting commercial products for military use but said that many program managers are of the opinion that this approach will not always meet military requirements. Mr. Young also commented on displays for military use. He cited a desire to incorporate larger displays into AWACS. Progress has been very limited and very slow; necessary ancillary investments are not being made. He expressed hope that industry would augment the initiative. He expressed concern about the slowness of the "time lines" for military system developments compared to commercial ones. He mentioned a DoD program (believed to be RASSP) that had made a good attempt to accelerate DoD system development to meet that of commercial development but stated that it had not been entirely successful. Mr. Young also raised the issue of how adversaries will harness commercial capabilities to their military advantage. He commented that this question must be addressed in developing the DoD investment strategy. In closing, he emphasized that DoD must carefully select the electronics R&D areas it will pursue in the future based upon meeting its most important needs – it must make the fundamental decision to get out of certain R&D areas.

Mr. John Hartman, of Hughes Aircraft Company, represented the Electronic Industries Association. Mr. Hartman first covered a number of concerns that must be addressed when considering the use of COTS for military applications. These include the recognition that there is no universal quality standard (i.e., each part and manufacturer must be evaluated for the application at hand), data sheets typically list performance only over limited temperature ranges, environmental effects may not be adequately addressed, effects of long term unpowered storage are often unknown. On the other hand, there are many advantages that may accrue from use of COTS. Some of these are the possibility of a significantly greater choice of packages, lower cost and lighter weight. He stated that contractors such as Hughes Defense Communications had used commercial/industrial components for military applications for many years. In particular, for Hughes, these included COTS components use in communications applications and in sonobuoys. He concluded by endorsing sensible use of COTS in military applications with the admonition that supplier selection and component evaluation are key elements when choosing commercial and industrial components to meet the DoD's needs.

The final speaker of the plenary session was Dr. Thomas McGill of the California Institute of Technology. Dr. McGill reviewed the results of a 1997 Defense Sciences Research Council study of Just in Time Electronics for Weapon Systems conducted for DARPA. Two specific technology areas were examined in considerable detail: A/D converters and multi-chip packages. The findings for A/D converters were as follows: **A COTS only approach to A/D converters will substantially limit advanced military information processing systems**. Empirically current A/D converters are "limited" principally by "sampling gate timing uncertainty." A fundamental understanding of "sampling gate timing uncertainty" and attempts to address the issues could lead to substantial improvements in A/D converter performance. "Out of the current box" approaches such as resonant tunneling devices, optically generated clock and sampling circuits, or circuits employing superconductors may be required to overcome empirical limits. Filters were also found to be important but were not included in the study.

For packages, it was clear that major system capabilities of revolutionary importance to the DoD would be unlikely to be met by the commercial industry. This part

of the study, led by Dr. Barry Gilbert of the Mayo Foundation, urged the U.S. to continue making large investments in military research and development to guarantee an ongoing military advantage. It cautioned that the U.S. is rapidly "eating its seed corn" i.e., the technology reserves built up during the 1960s - 1980s. Specifically, the study stated that **increased electrical performance from packages needed for use in DoD systems would only be achieved through improved manufacturing processes that lead to complete control of metal and dielectric structures, shapes, layer thickness and properties.**

Some key conclusions of the study were that **although the DoD must make hard choices about its S&T investments, there is no question that the military will require electronic components beyond those that are or will be available as COTS. Specifically, further work is needed to develop high power microwave components and A/D converters for microwave systems.**

Synopsis of Panel Sessions

Acquisition and SPO Perspectives Panel

Introduction:

The nominal purpose of the Acquisition and SPO Perspectives panel was to provide a forum in which past experiences, current activities and future plans, concerning use of COTS assets in military systems, could be presented and discussed by representatives of existing and developmental defense Systems Program Offices (SPOs). Panel membership was intended to include SPO representation from each military Service (Army, Navy, Air Force) plus a representative of the multi-Service JSF program and a member of an existing Service specific COTS steering group. The participating panel membership included Col. Chris Fornecker, Army Digitization Office; CDR Danny Stevenson, Navy Advanced Architecture Section, AEGIS program office; Robert Gibler, Air Force F-22 program office; and Niles Riegle, Director of Electronics Development, Naval Surface Warfare Center, Crane, IN. The representative from the JSF SPO declined to participate.

Each of the panel members was requested to address the questions listed in the Appendix for the Acquisition and SPO Perspectives Panel. The time allocation for this panel was intended to be approximately equally divided between panel member presentations and audience questions and comments. However, audience participation was very active and the discussion period extended beyond the time allotted. Speaker presentations are summarized below, together with an attempt to represent "the sense" of audience consensus.

Presentation Summaries:

Col. Fornecker described a recent Advanced Warfighting experiment, Task Force XXI, conducted by the Army to evaluate applicability of COTS digital componentry and software for tactical digital information use and communication. The experiment involved use of Pentium based COTS computers, Sun workstations, COTS routers and a variety of COTS software applications, interconnected via wire or VHF and UHF radio links into a "Tactical Internet." COTS assets were installed in locations ranging from relatively benign fixed sheltered locations; e.g., command posts, to mobile, high shock, high temperature range environment weapon platforms. Both standard "off-the-shelf" computers and "ruggedized" versions were evaluated during the exercise. The speaker noted that, in no case, were "system" operational or reliability requirements compromised to accommodate the use of COTS.

A variety of COTS software applications were also employed, ranging from vehicle movement tracking systems to Internet software wherein commercial standards and routing protocols were implemented. Software use problems noted resulted only from the restricted bandwidth of military communication systems, not from inherent COTS software limitations.

Possibly the most impressive application of COTS computing was provided by the application of a COTS computer to the "Paladin" fire control system. "Paladin" is a mobile artillery weapon system. No operational problems were noted and cost reduction for the fire

control system was reported to be 3:1 with a projected 6:1 reduction in the future. Additional cost reduction accrued for software maintenance was estimated to be about 2:1.

The conclusions from this experiment are:

1. COTS can meet most performance requirements.
2. COTS will reduce acquisition and life-cycle costs and reduce acquisition lead time over that associated with the use of custom military products, in large part because COTS assets are implemented using "open" commercial standards.
3. COTS provides an easier upgrade path.
4. COTS can play a beneficial role, even in demanding battlefield environments.

CDR Stevenson indicated that current use of COTS in the AEGIS system includes a variety of processors, connectivity equipment, displays and peripherals. AEGIS experience indicates that COTS assets can be employed to advantage in non-mission critical applications and even in some mission critical applications where they meet requirements. He noted that accommodation for use of COTS hardware has been facilitated by development of a "standard" cabinet enclosure ("Citadel") which provides flexible shock-isolated equipment mounting bays. A number of AEGIS system requirements which cannot currently be met with COTS assets were identified, e.g., the SPY radar antenna subsystem, SPY radar signal processor, and the fire control system illuminator. His presentation concluded with tabulation of a number of "use of COTS lessons learned" which seemed to indicate that COTS acquisition procedures in the "AEGIS Navy" are still a "work in progress" but that COTS can be expected to play an ever increasing role in military system development and acquisition. It is expected that formalized COTS selection methods will evolve over time.

F-22 experience with COTS use, as presented by Mr. Gibler, indicates that both commercial and industrial grade COTS parts can be selectively applied to this weapon system as long as appropriate qualification methods are used; e.g., testing, screening procedures. Some cost saving examples were presented which indicate that cost savings for specific parts can range from 2x to as much as 10x, without loss of operational functionality. The speaker noted that COTS use poses a variety of "new" issues for military system acquisition and maintenance. He specifically noted that mixed use of custom and COTS parts in military systems imposes requirements for "two level maintenance procedures" and that COTS parts usage carries some system weight and functional density penalties. Specific attention was given to implementation of selected military products using COTS processes and COTS semiconductor production lines; e.g., TRW's automotive semiconductor production line. Cost savings of 2:1 were noted from use of this methodology. The speaker represented use of COTS parts in military systems as a "fact of life" dictated by the recognition that these systems must be affordable. However, he indicated that acquisition methods must change to meet unique challenges associated with this procurement paradigm – and that this change is happening.

Mr. Riegle is currently a member of a COTS steering board whose mission is to address COTS policy on a NAVSEA-wide basis. He described some of the many questions and issues which will be addressed by this group. They include making acquisition management a continuous process, development of specifications for COTS parts, maintenance issues associated with (partly or completely) COTS implemented systems (absence of "normal" parts

lists, non-repairability, possible obsolescence of the line replacement unit concept, etc.), system configuration management with configuration control, development of processes for COTS parts selection, and a variety of changes which will occur in "technical management" of systems procurements. The scope of this undertaking clearly demonstrates the serious commitment being made by the Navy to systems implementation and maintenance in an age of increased use of COTS products.

Summary Responses to AGED Questions:

Overall there was little difference in the answers provided by the speakers to AGED questions. Their collective responses are summarized as follows:

Q1. All speakers indicated that current COTS acquisition policy definition and implementation are in a state of development within all Service organizations. It was clear from all presentations that use of COTS products, methods, and processes is considered by all military Services to be critical for realizing "affordable" military electronics systems and development of COTS acquisition procedures is a matter which will continue to receive considerable attention from the DoD.

Q2. Definition of COTS products closely follows the FAR definition; e.g., COTS refers to "products of a type which are customarily used for non-governmental purposes and which are offered for sale, lease or license to the general public."

Q3. A few "mission critical" system attributes were identified as requiring custom implementations; in general, these are functions which are associated with "front end" sensing or particularly critical and demanding signal processing requirements. However, this response was tempered by the acknowledgment that "COTS", as represented in these talks, included a number of product types ranging from pure COTS to "ruggedized" versions of COTS derived products. It was clear from the presented material that beneficial outcomes, in terms of system cost and maintainability, can be realized by treating "COTS" as representative of a broad range of capabilities, including methods, processes and products.

Q4. **In all cases, the system SPO participates in COTS vs. custom decisions but the primary selection process is implemented by contractors. It was also apparent that SPO's recognize that expanded use of COTS-based system implementations will require major changes in the methods and practices by which the military system acquisition process is managed.**

Q5. All speakers appeared to agree on the following lessons learned to date:

1. Substantial cost and time-to-deployment savings are realized from intelligent use of COTS components in military systems.
2. Expanded use of COTS components is and will continue to be a "fact of life" among military system acquisition agencies.
3. Carefully selected COTS products can meet stringent requirements of many military system applications; it is not necessary to compromise system performance requirements in order that beneficial consequences result from COTS based system implementations.

4. Considerable benefits (life cycle cost and maintainability) result from use of COTS products based on widely implemented commercial standards.
5. Increased use of COTS assets in military systems will impose significant culture changes on military system procurement/maintenance management procedures and these changes are still being recognized. Formalized methods and procedures for COTS use are in an active state of development within all branches of the military services.

Question and Answer Summary:

The general sense of the questions posed by members of the audience appeared to challenge the speakers' consensus message that COTS products can be effectively used to implement defense systems without compromising operational military effectiveness; e.g., "COTS products are, by definition, available to all buyers. How can the U.S. military expect to maintain combat advantage without exploiting the enhanced functionality provided by custom military products?"

The speakers' responses acknowledged that there are some specific military requirements which cannot now be met by COTS parts. However, Col. Fornecker, in particular, presented the argument that battlefield results are as much (or possibly more) determined by strategies and tactics employed to implement strategy. He noted that during the Battle of Britain (World War II), the British employed a tactic of holding their defense aircraft on the ground until "the last minute" to save fuel and to enable the use of more efficient attack tactics against radar-guided German bombers. Some in the audience suggested that an appropriate example of "decisive" impact of custom technology in this scenario was the British invention of the cavity magnetron, which enabled airborne radar and allowed Allied defense aircraft to better locate and target enemy aircraft. (Author's note: Unfortunately, what did not become apparent during this interchange was the time relationship of the Battle of Britain and deployment of magnetron implemented airborne radar. The Battle of Britain lasted from mid-1940 to early 1941. The British invention of the magnetron occurred in late 1940 and airborne radar became a decisive military asset only after the Battle of Britain was decided in favor of the Allied Forces.)

It appears, from the information presented by this panel of speakers that, at the SPO level, the U.S. military has relegated custom electronic technology development to only those system functions which, if implemented using COTS products, would measurably compromise system performance requirements. It also appears that the attendant cost and time to deployment savings which accrue from use of COTS are considered to be highly valuable benefits for U.S. military defense capability.

Defense Systems Industry Panel

The Defense Systems Industry panel included representatives from five major suppliers of defense systems: Lockheed-Martin (Sanders Division), Raytheon, TRW, Northrop-Grumman and ITT Defense. Each panelist made a short introductory presentation to set the stage for further discussion. Summaries of these are as follows:

Dr. John Kreick of Sanders emphasized that system engineering considerations will, of necessity, change significantly from those traditionally employed in the development of DoD systems. For example, the use of open architecture design will become increasingly important. Design margins will have to be larger. System developers will have to form closer relationships with COTS vendors and, perhaps, become α and β test sites for component evaluation. Comprehensive databases of component information will have to be assembled. Software considerations will play an increasingly large role. Tremendous cost savings may accrue from the use of commercial software but only if operating system changes can be accommodated without deleterious effects on the overall system. In the past, detailed design to MIL-specs provided a safety margin for DoD systems. A major challenge of effective COTS usage will be to either provide sufficiently ruggedized individual components or provide a ruggedized housing to meet environmental requirements. Dr. Kreick stressed the fact that although COTS usage often provides a significant initial cost savings, a much longer logistics tail will occur. He further stated that **although use of COTS will be dominant for digital applications, microwave wideband components for DoD systems will always have to be custom-made as will most electro-optical parts. With regard to packaging,** he said that **COTS developments must be closely monitored and used whenever appropriate. However, it is highly likely that, for military applications, custom packages will be needed to provide necessary functionality and to accommodate military system constraints.**

Mr. Randy Smith of Raytheon discussed a large number of considerations that must be addressed when selecting components, either COTS or custom parts. These included package style and footprint, supplier viability, uniqueness of technology and intellectual property aspects, logistics support/life cycle costs, the need for common operating environments and standard interfaces, an assessment of the reliability of each component both in operating and storage environments, availability of the supplier base, acquisition cost and development cycle type, flexibility of system performance requirements and anticipated production volume/minimum buy requirements. He commented that Raytheon often adopts the approach of using multiple cycles to develop its products; final products may take 6 years to reach fruition but releases occur more frequently, approximately every 18 months. He stated that the "bottom-line" in component selection was ability to meet performance requirements and that use of COTS must be tempered with an effective system level risk mitigation strategy. Some attractive payoffs of COTS usage are reduced non-recurring-engineering (NRE) costs for component development, broader component availability and increased opportunity for common interfaces and operating systems. Mr. Smith agreed with Dr. Kreick that **DoD support for custom components would be essential for microwave devices and circuits and for optical components used in missiles.**

Mr. Mark Bever of TRW discussed the use of COTS parts from a MILSATCOM perspective. He cited the following system features as those of highest importance: security, assured access, anti-jam protection, nuclear protection, terminal locations and facilities, and required coverage. He noted that in the MILSTAR system about 60% of the components used are derived from commercial components. Mr. Bever supported the contention that **DoD must continue its investments in millimeter-wave components, particularly for power MMICs and phased array antennas.** He also cited **a need for continuing investment in radiation hardened digital ICs.** In addition, he noted the pressing **DoD need for investing in high performance A/D converters which will not be available as COTS.** Mr. Bever commented that commercial (satellite communication) systems will drive military expectations and their development will reduce military system costs but, military systems will always require additional security.

Mr. William Eikenberg of Northrop-Grumman cited the importance of performance discriminators vs. adversaries achieved through the use of state-of-the-art components. He embraced the use of commercial practices and processes to create critical non-standard components. As an example, he pointed out that in one UAV development approximately 65% of the parts were COTS. He suggested that perhaps 50% of RF parts could be COTS and, eventually, 100% of the non-RF parts.

Mr. Eugene Hammer of ITT also endorsed the use of commercial processes. He cited the importance of close interaction between system suppliers and component suppliers to assure that requirements are met.

The following major perspectives and conclusions arose from the panelists presentations and subsequent discussions with the STAR attendees.

A. MAJOR PERSPECTIVE #1

- **Electronics technology can significantly leverage U.S. military superiority in the 21st century only if S&T investment is enhanced and continues.**

The history of the last 20 to 30 years of the 20th century, incontrovertibly showed U.S. military superiority based increasingly on superior tactical and strategic electronics subsystems. This outcome was rooted in a DoD electronics investment policy of 50 years, the first half of which also spawned a worldwide commercial electronics industry, now the largest industry as we approach the 21st century.

An important question, in this age of DoD downsizing is: **"Does the policy of DoD (S&T) electronics investment need to continue to maintain 21st century defense superiority, given the large commercial electronics industry?"**

This issue is often oversimplified, to coincide with the increasing use of COTS (commercial-off-the-shelf) components and modules. There is no question that maximum COTS usage is economically useful to DoD and will provide enormous cost savings, perhaps as much as 50%. Therefore, use of COTS is essential and necessary to maintain

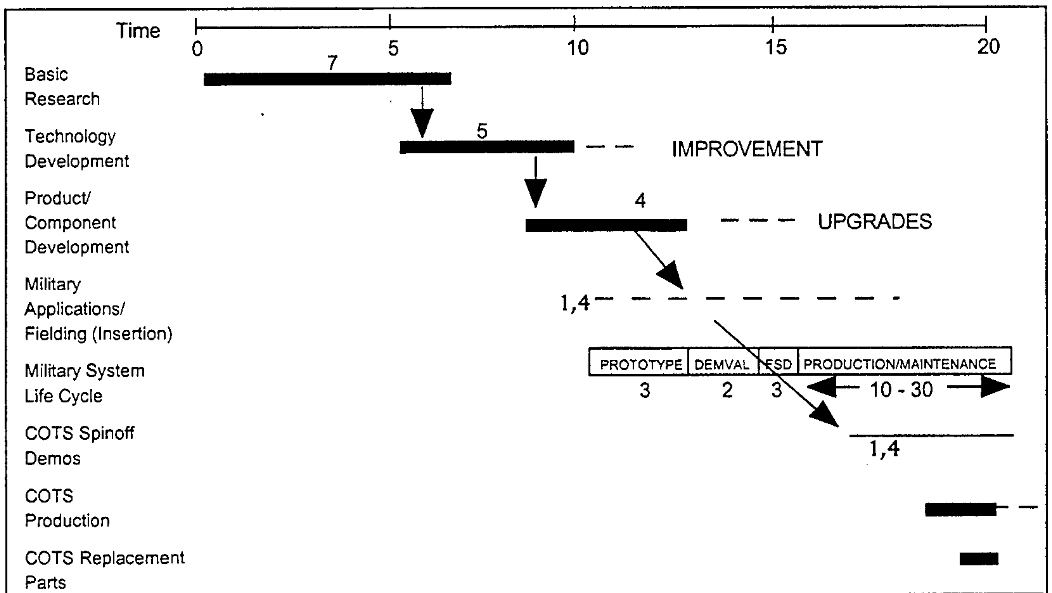
an efficient U.S. Defense posture. But the larger question of "How to Maintain Defense Superiority" leads to a different answer:

COTS alone is insufficient for superiority.

Although COTS usage will continue to expand, the need for military-unique electronic components to maintain superiority will not disappear. This rationale is firmly based on unique military sensor performance as well as the demands of unique mobile platforms and missions. To understand this important conclusion, refer to Table 1 (Military Unique Electronics Technologies) and Figure 1 (Electronics Technology Timeline).

Table 1. Military-Unique Electronics Components Technologies – 2000 to 2020

Examples
• High performance, high frequency microwave electronics (2 to 200 GHz)
• High bandwidth analog-to-digital converters (0.5 to 20 Gsps)
• Devices and components for operation at very high temperatures
• Electro-optic IR imaging arrays, EO components for missiles, and related components
• UV/IR Detectors
• Radiation-hardened integrated circuits for space
• High power RF sources - solid-state and vacuum (5 to 100 GHz, 1 to 1000 Watts)
• MEMS for miniature UAV
• Electronically steered antenna arrays for multiple agile beam forming.
• High performance, highly integrated packaging and interconnect MCM technologies



NOTES:
1. COTS is the fallout, not the driver, for military-unique technology
2. COTS can often provide replacement parts for fielded systems
3. Unique high leverage military-unique technology requires DoD funding until COTS spinoff occurs in 12 to 15 years
4. Defense systems superiority most often traces to important military-unique electronics technologies

Figure 1. Electronics Technology Timeline (Typical) – Military Use First

Without an enhanced continued U.S./DoD S&T investment in these types of military-unique technologies, the military superiority the U.S. has enjoyed in the latter part of the 20th century will gradually disappear in the 21st century, simply because superiority translates to time lead. This 5 to 10 year time lead must be provided by unique technology that is not available to potential U.S. adversaries, and difficult to reverse engineer in a short period of time.

During the 1990s, the DoD S&T investment in military-unique electronics technologies has eroded more than 50%. It now appears to be insufficient to provide decisive military time-advantage leverage for systems of the early 21st century.

The System Industry Panel recommends:

⇒ **A clear U.S. and DoD long-term policy of support for robust military electronics science and technology investment, traceable to military superiority needs should be established by the DDR&E with Service concurrence by October 1, 1999 traceable to military superiority needs.**

⇒ **Definitization of such technologies and funding levels**

⇒ **Responsibility assigned within DoD, with coordination and contributions from other government agencies (NASA, DoE, DoC)**

B. MAJOR PERSPECTIVE #2

- **A new defense system acquisition process/paradigm is needed for efficiently expanding COTS cost savings while providing and maintaining superior defense systems.**

The critical elements of the new COTS Process/Paradigm are as follows:

1. <u>FLEXIBLE SYSTEM/MISSION TOP LEVEL SPECIFICATION PROCESS</u>
   This incorporates cost as fixed independent requirement and system performance/features as a dependent variable requirement.

   <u>Benefits:</u>
   1) Contractors will be allowed the freedom to architect, design, and develop a total system approach of known cost and be allowed to tradeoff expensive performance and features for cost savings.
   2) Final configurations will be agreed upon with full participation by the DoD Program Manager.
   3) Intelligent decisions can be made concerning appropriate levels of incorporation of COTS and military-unique technologies to achieve the best balance between cost and performance.
   4) Provision/strategy for life cycle maintenance and upgrade must and will be included and planned for in advance.

Features:

1) System Engineering Process for incorporation of COTS hardware and software.
2) Elimination of unnecessary over specification of subsystem requirements and military standards.
3) Development and implementation of new system program processes and milestone standards which encourage and enforce the new paradigm, driven by the system contractor and SPO.
4) Incorporation of a pre-planned life cycle strategy with built-in milestones and "hooks" for system/subsystem/COTS component upgrades.

2. COTS SYSTEM ENGINEERING AND DEVELOPMENT PROCESS

Industry/DoD can develop a rapid turnaround, highly analytical/CAD intensive system engineering discipline for COTS incorporation and tradeoff at all levels (component/board/unit), both hardware and software.

Benefits:

1) Reduced system development cost and schedule.
2) Required dissemination of the system CAD tools that are funded by DoD.
3) Robust virtual system and hardware simulation, which reliably predicts cost and performance over a full 20 to 30 year life cycle, including planned upgrades.

Features:

1) New System Level/CAD "Open" Architecture Simulation Tools for major categories of defense subsystems – radar, EW, communications, imaging, fire control, etc., which permit rapid parameter performance/feature/cost tradeoffs.
2) Multilevel Macrocell Design Synthesis CAD Tools, which permit substitution of fixed COTS hardware and software library elements (all functional levels from component to board to box), in combination with variable elements, to conduct rapid iteration design. This will allow extrapolation of COTS usage to military environments with provisions of margin for life.
3) Cost Modeling CAD Tools and processes that provide full and accurate prediction of non-recurring engineering, manufacturing, and life cycle/upgrade costs. Both COTS and military-unique component cost elements, fabrication, assembly and test cost will be modeled.

C. MAJOR PERSPECTIVE #3

- **DoD/contractors should establish an industry-wide consortium-infrastructure and formal association to facilitate both COTS processes/database and military-unique technology policy, methods, and status.**

Benefits:

1) Clearly establishes DoD top level intent and policy for COTS component exploitation and simultaneously defines plans for military-unique S&T funding policy and expected output.
2) Reduces industry individual duplication of effort for all aspects of COTS infrastructure creation and maintenance – system suppliers and vendors.

3) Provides a means and forum to maintain COTS vendor interest to supply DoD, to reduce risk and uncertainties.
4) Exploits dual use.

Features:
1) A COTS vendor database would be maintained by a DoD information agency and shared by all contractors. It would include product specifications, test data and (on a nondisclosure basis) future product plans.
2) A national COTS Conference and Exhibit, driven by DoD, attended by DoD, system contractors, and COTS vendors, would be used to proliferate information about DoD policy, COTS CAD Tools/Processes, database sharing, and lessons learned. Multidisciplinary sessions, technical papers, panel discussions, vendor product exhibits, subcommittee sessions, and organizations would be established for continuing dissemination of information and discussion of COTS infrastructure issues such as IC CAD, Module CAD, System CAD, packaging, software standards, materials, obsolete part replacement methods, qualification and testing, and model year upgrade processes.
   Suggestions: a. Expansion of the DoD GOMAC conference.
   b. Establishment of an EIA division for self-administration by industry.

3) **A National Defense Electronics Science and Technology Conference – organized by DoD management with multiple agency participation. This would provide a forum for presenting DoD Electronics S&T policy, programs, long-term plans and results. It would allow a two-way discussion with industry.**
   Suggestion: Expansion of DARPA/NIST conference with participation of major DoD Laboratories and Reliance panels sponsored by the DDR&E.

D. MAJOR PERSPECTIVE #4

- **The balance between COTS exploitation and and military-unique electronics technology needs in the 21st century will vary with type of platform and segment of the weapon system (sensor-processor-network) being built.**

Components Suppliers Panel

Introduction:

Component suppliers are a distinct segment of the COTS community differentiated from the Government by a profit making business motive and differentiated from defense system companies as a piece part, mass production enterprise. Today, component suppliers do not generally furnish products exclusively for defense systems; rather, they find it cost effective to maintain a vigorous commercial business with military products supplied through a separate division or office or subsidiary. Most electronic component suppliers focus only on commercial business, driven by its much larger business base relative to that for satisfying defense needs.

Component suppliers to the defense community span a range from furnishing strictly commercial catalog parts to producing fully customized parts built to government military specifications. Intermediate between these extremes are firms which tailor commercial parts to meet augmented requirements. Some firms may tailor processes to produce higher quality military parts or may design a dual-use production process that serves both commercial and military needs. Common to all of these variants is the basic business profit motive; it will determine the approach each firm takes to serve the defense establishment.

This panel was invited to address the future components supply issue. **The ability of the Government to obtain current and new components and electron devices which meet system requirements is constrained by commercial business operations.** The purpose of the panel discussion was to explore the manner in which these constraints impact government procurement of suitable COTS parts and what the government R&D plans are for developing innovative new devices which ultimately will have to be produced in a cost effective manner.

The four panelists represented slightly different business segments as follows:

Mr. Joe V. Chapman	Military Products Division Government Relations/Facilities Manager of Semiconductor Group Texas Instruments
Mr. Brian D. Hagerty	Military and Commercial Parts Director; MSP Product Line Harris Corporation
Mr. Gerald E. Servais	Mainly Commercial Parts Manager, Parts Research & Test Development DELCO Electronics
Dr. John Vaughan	Military (mostly) and Commercial Vice President, Technology Marketing and Business Development M/A-COM

TI and Harris serve, in varying degrees, both commercial and military markets. DELCO is primarily an auto parts manufacturer supplying only COTS parts to the Government. M/A-COM has a military emphasis. The panel was organized to address the 3 questions shown in the Appendix on page 45. A lead panelist assigned to a particular question described the position of component suppliers for the general discussion. These discussions are summarized below. Findings have been extracted from them.

Discussion of Questions:

Q1. What is your definition of COTS components? What does the term COTS mean to commercial suppliers, military suppliers, and captive suppliers? (Hartwick)

Commercial suppliers do not generally distinguish a category of parts entitled COTS. Standard parts are typically identified by a number and a spec sheet. If a part is made on a QML production line, military part qualification is automatic. A part is no longer considered commercial if tailoring of the spec or the package is done to meet specific military requirements. There seemed to be little disagreement about the answers to these questions. Differences appeared to be more a matter of style than substance.

Q2-a. Can the DoD develop advanced systems without performing advanced component development and making use of these advanced components? (Servais)

Servais expressed the position that the quality of many automotive electronic parts is already adequate for military use. He cited the results for the Engine Control Module described in Figure 2. The point was made that auto makers are introducing a great deal of standardization into the specification of parts. Utilization of these parts eliminates costly development for new system designs. It was suggested that military buyers could avoid development of many new parts by understanding, in detail, the performance characteristics and specs of the >1000 automotive parts that are now available.

It was suggested that the DoD can influence commercial firms to build advanced components by making early investments during the R&D phase of a product's development cycle. However, firms can only be influenced to change their manufacturing processes to accommodate the needs of new military devices if they project a sufficiently large volume market. Investment of capital by industry has to be justified by return-on-investment (ROI) analysis.

Q2-b. Will it be possible for the DoD to gain information about advanced commercial component developments, and the products that will result, in sufficient detail to allow the design of systems that incorporate them as these products become available? (Hagerty)

The panel agreed that the answer to this question depends on projections of future DoD business. If the DoD were to invest in R&D for an advanced part and planned a large volume buy of this part, the answer would be "yes," provided that the company wished to retain military business. Extending R&D for an advanced part into qualification and production is expensive. The ability to sustain production processes is strongly dependent on the degree of synergism with

high volume commercial part sales. "No" is the answer if non-standard technical data are required or if additional characterization data is necessary to model military system operation conditions such as radiation hardness levels or extended temperature performance. Suppliers will always supply standard data sheet information.

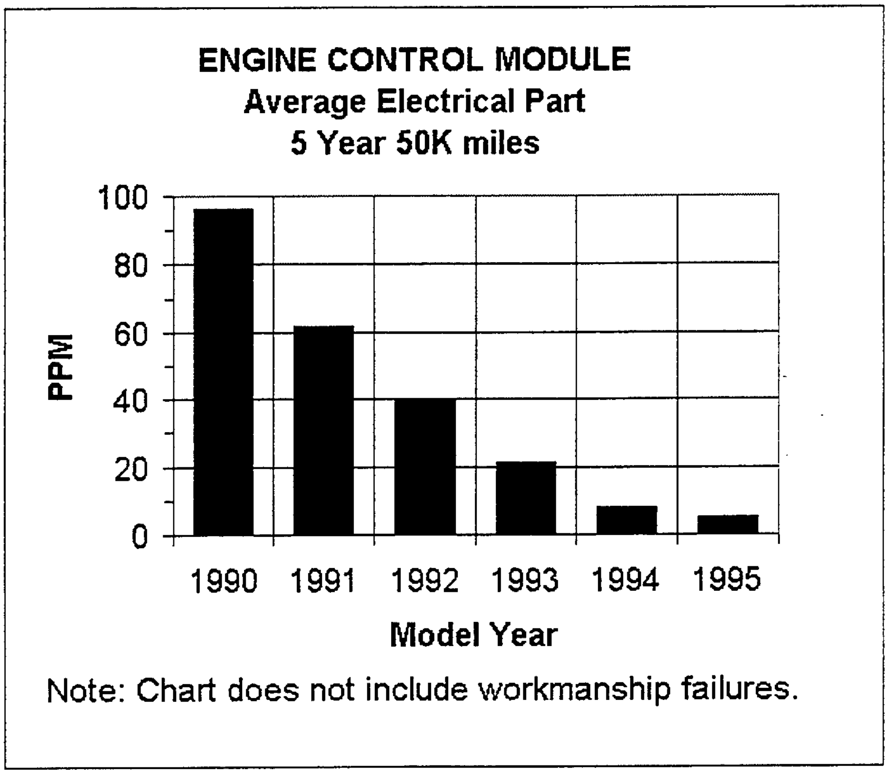


Figure 2. PPM Failure Rate vs. Model Year

Q2-c. Is it likely that commercial suppliers will develop any military unique components without direct funding support and guidance from the DoD? (Vaughan)

Unlikely! Generally the commercial ROI is poor, the customer base is small and the component suppliers are usually competing with system houses. Discussion of larger DoD single part orders for arsenals brought out the need for more analysis of the total logistics strategy for COTS; it was noted that regardless of the logistics strategy adopted, level of production still had to be sufficient to make the business viable for component suppliers. An important commercial phenomena called "churn", defined as buy a million....sell a (prime priced) thousand....sell the rest as surplus, has to be taken into account in developing a logistics strategy for COTS. It is also a consideration for venture capitalists exploring the possibility of transitioning a military R&D company into one addressing the commercial marketplace.

An alternative to direct government funding of component suppliers for development of needed unique parts was suggested. In the proposed scheme, system/component supplier consortia would be set up with DoD technology base funding provided to the system house members. A sharper focus might be achieved in this way that would result in reseeding the

industry. Although not explicitly stated, the stronger system business base would have to be sufficient to entice and bolster the component business.

Q3. Will technology for COTS components continue to develop at an acceptable rate without continued investment by the DOD in the development of leading-edge electronics? What is the history of current COTS products and expectations for new COTS products that will emerge within the next decade? (Chapman)

It was pointed out that the QML component houses (TI, Harris, National, Analog Devices) supply the military with ICs and provide leading edge technology; new part introductions occur each year. However, the DoD buys only ~1% of the total electronic part output and, hence, does not have a significant influence on the business. Some suppliers will only take DoD investments if the product DoD desires will also have significant commercial sales. Some mention of consortia formation was made, but the continued pace of COTS component development is driven by the commercial market.

Findings:

1. Component suppliers of COTS and advanced/unique military parts are viable for support of DoD missions as long as the business is profitable to them.

This point came up over and over in the panel discussion in the context of the particular question under discussion and seems to apply regardless of the relative percentage of military and commercial business.

2. DoD logistics strategy needs to fully account for the business positions of Finding #1 in terms of volume buys of COTS or military unique parts.

3. DoD needs to support the development of advanced electronic parts unique to military systems and find a funding structure for sustaining the qualification and production of these parts through formation of consortia, flexible manufacturing, or other means that provide the necessary business incentive.

Government cannot otherwise gain the attention of commercial suppliers.

Science and Technology Perspective Panel

Introduction:

Defense sponsored research and development in electronics, over the last fifty years, has been the primary source of science and technology knowledge from which extraordinary advances in electronics technologies have sprung for both military and commercial purposes. The commercial application of electronics high technologies has formed the basis for great advances in almost every part of our society and has become the engine of the world economies. Defense, as is well known, also has gained very substantial rewards, in terms of its capabilities, from its S&T investment. At issue today is the appropriate level and application of Defense sponsored research and development in electronics in light of the significant application and capabilities of commercial electronics products in military systems. **The lack of investment by the commercial market place for all but mass market commodities ensures that such products will not only be available to us but also to our potential adversaries.** The Science and Technology Perspective Panel representing a cross-section of the performing community – industry, academia, and the DoD and its services – was well suited to address these issues.

The Panel first made opening remarks followed by a detailed discussion of "Questions for the S&T Perspective Panel", given in the Appendix on page 47. The Panel also interacted with the floor after each question. Highlights of the opening remarks are as follows. Professor Thomas McGill noted the great change in the conduct of science and technology that is now on-going between industry, academia, and government. He also commented on the important contributions made by the OXRs and DARPA in avoiding technology surprise and their large contribution to graduate research. Specifically, he commented upon the production of students, sponsored by the DoD and its services, who entered the work force and made, in aggregate, large contributions to national security. Noel MacDonald gave the DARPA-ETO perspective as one of finding means to achieve higher levels of integration of diverse functional components (e.g., MEMS and silicon ICs) to perform real time sensing functions over the entire frequency spectrum. Michael Andrews, representing the Army, pointed out the relatively small volume component buys made by the military and their diversity. Although the Army requires that its electronic systems function at an extraordinarily high level of reliability in a military environment, it must also weigh cost versus performance during the selection of components. Bobby Junker, representing the Navy, made several salient points. He noted that DoD systems requiring extremely high performance usually dictate requirements for DoD to drive the enabling technologies by supplying R&D funding. Often, spin-offs from these high performance component developments are later adapted by industry for commercial applications. He also pointed out the **reluctance of industry to lead the development of major paradigm shifts in electronics technologies. Industry**, he pointed out, **will not pursue long-term, high-risk R&D**. He also expressed concern about providing adequate logistic support for COTS components that rapidly become obsolete in the commercial market place. Michael Polcari, representing IBM, expanded upon Dr. Junker's logistics concerns by pointing out that, in the commercial computer and information technology hardware business, speed of integration (i.e., bringing new products quickly to market) is crucial to market success. He further commented that, in the high tech electronics business, making a profit is insufficient justification to invest

new capital. Business growth must also be present. Dale Hutchinson, from Lockheed-Martin Federal Systems Group, reinforced earlier comments about logistics issues, specifically as they impact configuration control. In his view, prime contractors would have to maintain systems that depend heavily on COTS components throughout their life cycle. Tim Kemerley, representing the Air Force, noted that his Service was under great pressure to develop affordable electronic components. He felt that it is necessary for the services to not only learn how to apply COTS but also to develop "long lead items", for as yet undefined systems of the future, that industry will not pursue by itself. He noted that many of today's COTS components were developed as a result of prior DoD R&D investments. In closing, he commented that the Services need to maintain a core technology base to meet future military specific component needs and to develop dual use COTS components.

Discussion of Questions:

Q1. What areas of S&T will the commercial marketplace dominate? What areas will commercial suppliers make significant investments in over the next 10 years? How can DoD best access this knowledge base for its purposes?

The Panel stated that **information technology will be an electronics technology area dominated by the commercial marketplace**. The range of technologies spanned by commercial developments will range from communication products to enabling integrated circuits. Industry will make significant investments in these areas. **However, "high end" RF technologies, of great importance to the DoD, will not be driven by industry. DoD must pay for necessary improvements in this technology area.** COTS mainstream areas in which significant spin-on to military needs can be expected include: Silicon IC Technology; CAD tools, languages, and environments; networks and protocols; semiconductor processing equipment and starting materials; measurement and test equipment; packaging technology; optical fiber technology; and flat panel displays. There is an inevitable slowing coming in the ability to scale CMOS ICs because of device physics and optical lithography limitations. **DoD should remain active in silicon research to ensure the availability of a national industrial base.** DoD can best access this commercial knowledge base in two ways. The first is by establishing strategic relationships with suppliers. The second is by early involvement (i.e., government investment) in key emerging technology efforts that allow steering these efforts toward meeting defense needs. The Panel also noted the **pull back in corporate sponsored long-term research** (greater than five years).

Q2. What areas of S&T will be the ones that the commercial marketplace will not dominate? What areas, likely to be of considerable importance to the DoD, will commercial sources not make significant investments in? What approach is best for the DoD to pursue in order to perform necessary R&D in areas of crucial importance that the private sector is not motivated to pursue: Use of Government laboratories? Contract R&D with Academia? Contract R&D with Academic-Industrial Consortiums? Contract R&D with defense industry contractors? Other methods?

In general, the industrial sector is very averse toward taking economic risks and toward making investments that are not likely to provide an immediate return. As a

consequence, it will not make the necessary R&D investments in high risk technologies without substantial government financial support. DoD historically has held a dominant position in providing funding for basic research in the physical sciences, particularly electronics research. The results of this long term funding has led to many situations in which DoD has been the first and largest user of a new technology. Its applications are often eventually followed by commercial spin-offs. This point is shown pictorially in Figure 3.

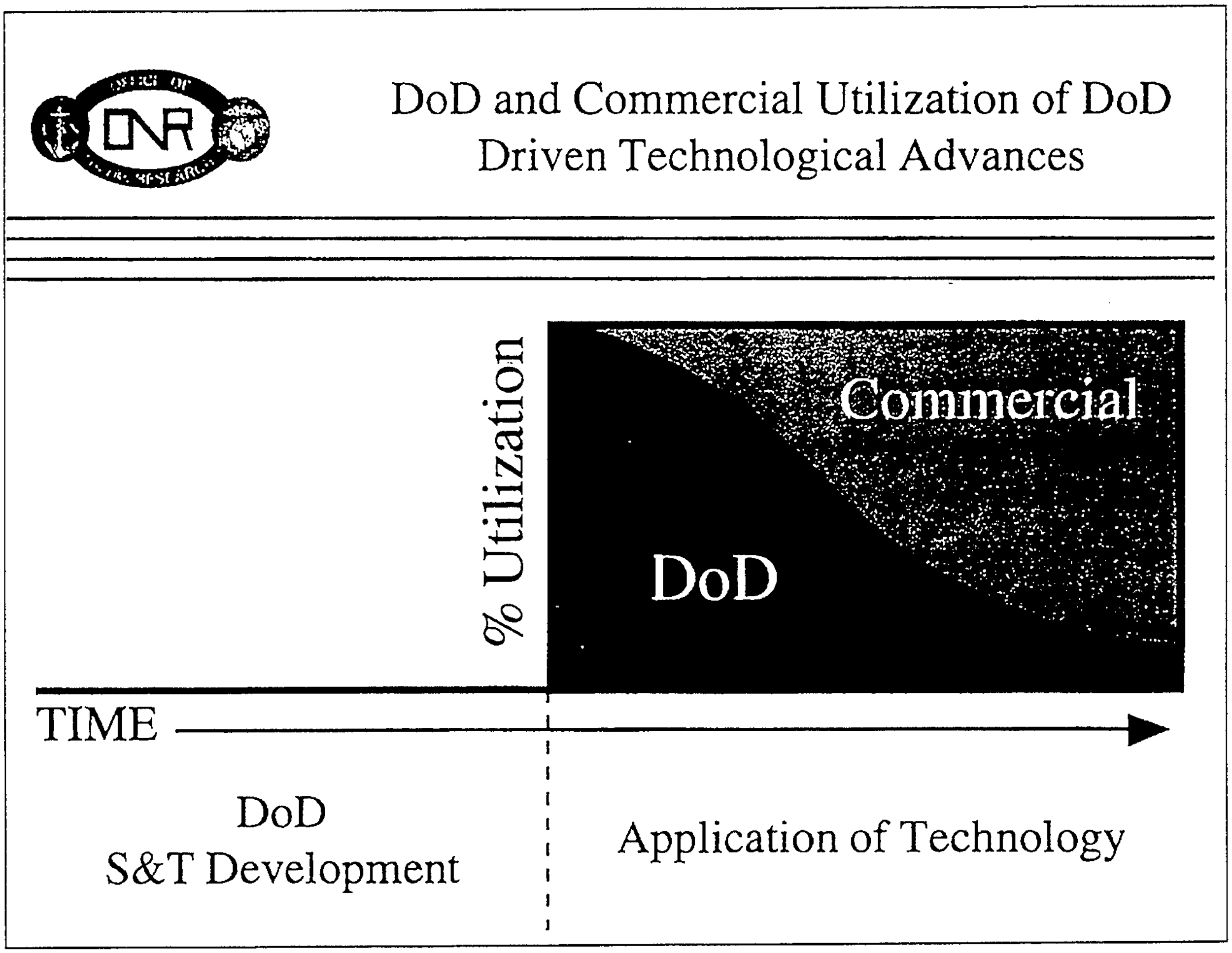


Figure 3. DoD and Commercial Utilization of DoD Driven Technological Advances

The commercial market place will not meet DoD needs for highly integrated, high performance sensors. Specific component technologies that DoD must support include: high power microwave solid state and vacuum electronics; high speed and high resolution analog-to-digital and digital-to-analog converters; very high speed signal processors; high frequency components-millimeter waves; high temperature devices and components; multi-octave frequency bandwidth components; UV/IR detectors and focal plane arrays; E-O sources; mixed signal digital/microwave/electro-optic ICs; phased array antennas; and highly integrated packaging and interconnect MCM technologies. It was also pointed out that technology development must include plans for transitioning results to manufacturing in order to avoid shelf life obsolescence. The plans for the transition to manufacturing must also

take into account the timing and magnitude of potential markets. Total life cycle cost reduction through the early use of R&D most also be an important consideration for investment.

Q3. Are the current DoD designations for RDT&E (i.e., Category 6) still relevant today and is the implied model of those designations still valid (i.e., serial transition of knowledge, new capability, and results from basic research to fielded demonstrations)? If not, what alternatives might be more attractive (e.g., S&T investments grouped by time to achieve results)?

The Army RDT&E process was described. It includes Strategic Research Objectives for 6.1 programs and Strategic Technology Objectives for 6.2 and 6.3 programs. The Panel had no opinion as to the continued applicability of the Category 6 designations.

Q4. What are the implications for defense electronics R&D in light of defense industry consolidation?

Several concerns were presented that have implications for deliberations concerning the appropriate use of COTS components. The industrial point of view is that the DoD must continue to supply significant R&D funding to the large consolidated industrial military manufacturers. This is seen as necessary because stockholders of these companies expect double digit returns on their investments. **The fact that government funds are being saved through consolidation also means that these companies' use of their internal R&D funds, also declining because of declining DoD procurement in general, will be tightly focused on programs that are perceived to have immediate impact on the growth of the company. This will limit future strategic investment making DoD funding in this category imperative.** A DoD concern is that the lack of competition for DoD business, resulting from consolidation, will lead to a decline in companies' internal funding for innovative work, a loss of access to independent validation of new concepts and technologies, and a loss of innovation in new systems. Since DoD S&T funding is also declining, it is likely that a major decline of internal R&D by industrial defense contractors may also occur. This will further inhibit innovation and force a COTS solution by default. **Industrial response to this concern, expressed at the STAR, was that, in order to grow their business and gain a larger market share, industry must pursue tightly focused efforts. This strategy may not be in the best long-term interests of the DoD.**

Q5. How is the international S&T environment for electronics R&D likely to evolve over the next ten years? What nations/geographical centers will serve as resources for R&D capability? How can the DoD best exploit these capabilities? Are international S&T activities a threat or concern of any kind?

The DoD must sponsor or participate in international R&D, not as buyers of products resulting from the S&T knowledge base of others but as partners that become technically smart as well. In this way, full value to the DoD can be achieved for the investment it makes in sponsoring some foreign R&D.

Insertion Lessons Learned Presentations

The final set of panelists at the COTS STAR were program managers from the Army, Navy, Air Force and DARPA who shared their experiences of using COTS components in the systems that they were associated with. Panelists included Mr. Kevin Richardson, a fire control radar systems engineer from the LONGBOW program office, Mr. J. J. Lacamera, Deputy Program Manager, Undersea Weapons Program Office (PMS 404B) who spoke about the ADCAP torpedo, Mr. Don Hartman of the Air Force's C-17 SPO, and Major Don Lacey of DARPA's HAE UAV program office who spoke about DARKSTAR. A summary of their comments follows.

LONGBOW

Experiences encountered in attempting to use COTS for the Longbow Fire Control Radar were mixed.

A positive experience was encountered during development of the Longbow radar frequency interferometer:

- COTS technology was used.
- An estimated savings of $12M accrued.
- There was a significant performance improvement.

Negative experiences were, unfortunately, also encountered. Some of these were:

- Inability to purchase various COTS parts as system production progressed because they were discontinued by their manufacturers. Each time this problem occurred it was necessary to redesign the printed wiring board.
- Similar problems with the MIL-SPEC parts used in the Longbow Ka-band transmitter. During EMD, a vendor notified the prime contractor that key MIL-SPEC parts would no longer be manufactured. This necessitated redesign. MMIC technology was inserted; available COTS parts were not suitable.

General recommendations concerning COTS use are as follows:

- **Open architecture should be utilized for designs.**
- **Continuous monitoring of the number of sources for a given part (DMS issue) should be made a risk element during milestone reviews; funds should be provided to ameliorate this type of risk.**
- **COTS technology should be considered at the beginning of a system development project.**
- **Performance requirements that hinder the use of COTS should be carefully reviewed to see if they are essential.**
- **Parts interchangeability is an important consideration.**

ADCAP (Torpedoes)

Mr. Lacamera divided torpedo designs into four sub-areas: propulsion energy subsystems, sensors, signal processors and high powered computing subsystems. For propulsion energy subsystems, which have very high power densities, use of COTS is not possible. There are also no suitable commercially available sensors. However, there are some COTS signal processors that are worthy of consideration and use of COTS is planned for the high-powered computing subsystems. Mr. Lacamera offered the general observation that as one moves down the signal path away from the sensor, use of COTS becomes more viable.

Current efforts related to the use of COTS in torpedoes include the following:

- An attempt to standardize architecture across product lines
- Use of common processors
- Use of common software

However, **the Navy torpedo design team has observed that "(use of) COTS isn't as easy as advertised."** Some difficulties encountered were as follows:

- The impact of "simple" parts substitution did not become apparent until the torpedo under development was undergoing "in-water proofing" testing:

  ⇒ In water, there were problems with noise on all channels; these did not occur during preliminary testing

  ⇒ Documentation showed that a given (COTS) part was a one-for-one replacement for a similar part used previously – it was not! This caused major torpedo performance problems and necessitated rework

- Use of COTS replacement parts can also cause problems for equipment users.

  ⇒ For example, updated models of meters and instruments were procured. The new models had different knobs and dials which, in turn, required changes in fleet maintenance and torpedo building procedures. The problem was discovered after the new equipment reached a point where it was ready for deployment.

General observations were as follows:

- Acquisition reform and COTS insertion can provide reductions of system development time and costs
- However, no change is ever "too minor" until proven to be so
- The design and production teams must fully understand the impact of all changes on the overall system

- Testing approaches must be tailored to identify the impact of component changes on system performance early in the production process
- "It hasn't worked until it works"

C-17

Mr. Don Hartman stated that COTS was used for the C-17 mission computer and for the wireless intercom system. Problems were encountered with the latter. The intercom system was found to be susceptible to electromagnetic interference (EMI) during full testing at Patuxent River. It also operated at frequencies with restrictions on their use outside of the United States. Its battery charger was not compatible with the airplane. Mr. Hartman concluded that using **COTS "as is" doesn't work well for military applications, but work-arounds are sometimes possible.**

DARKSTAR

Major Lacey gave a brief introduction of the factors driving DARKSTAR design. An upper limit of $10 million (in FY 94 dollars) was set for the total cost of each DARKSTAR. Mostly commercial practices and standards were used. Substantial amounts of COTS were used in the Synthetic Aperture Radar (72%) and the Integrated Sensors Systems (61%).

APPENDICES

TECHNOLOGY NEEDS AND TRENDS (1998-2020)
STAR AGENDA
TERMS OF REFERENCE
QUESTIONS FOR PANELISTS

Technology Needs and Trends (1998 – 2020)

1. Digital Technology (logic, memory, processors, controllers)
   a. Commercial
      - Amazing and rapid commercial progress will continue through year 2010, with a 50x performance/cost improvement expected.
      - A rapid product obsolescence cycle of 18 months will continue through 2005, but will slow to 36 months by 2010.
      - Custom ICs will migrate from gate arrays to standard cells (including macrocells and supercells) and FPGAs.
      - Fewer custom ICs will be needed.
      - Design/CAD/software complexity will dominate DSP core development; use of embedded processors will increase.

   b. Military
      - **Military Space Rad-Hard/Rad-Tolerant digital ICs will continue to be needed and used as unique technology. However, usage of rad-tolerant (COTS process, unique cell library) chips will increase particularly for spares. The cost and performance gap between rad-hard and rad-tolerant/COTS will increase. This will promote development of design methods and a COTS infrastructure for rad-tolerant chips. Continued DoD S&T investment will be required for both.**
      - **High Speed/Low Power Logic - will require unique material and device technologies tailored for specific military applications. 1 to 20 Gbps clock rates will be required.**
      - Use of digital COTS components will increase from 80% (1997) to 100% (2010) on all military platforms, with a few exceptions as noted above. Digital COTS usage will increasingly also encompass module and board levels although at less than a 100% level by 2010.

2. Analog/Multifunction Technology (dc - 500 MHz)
   a. Commercial
      - Analog IC technology (baseband linear, nonlinear, power function) progress will advance by 10X by 2010, limited by fundamental noise and power density factors. CMOS will dominate over bipolar devices, except where maximum precision is required.
      - A Multifunction ("commercial system on a chip") trend will emerge and increase, dominated by consumer applications. It will provide a process and design capability which combines analog, digital, and some RF functions (<1 GHz) on the same chip. Library techniques will be established for users.

   b. Military
      - **Some rad-hard analog IC military-unique technology applications will continue, primarily for nuclear missiles. However, it will be problematic to find sources for dielectrically isolated analog ICs. Instead CMOS SOI**

will be increasingly used, with a common fabrication process for rad-hard digital ICs.

- **Analog-to-Digital Converters. Wideband (>0.5 Gsps) ADCs will continue as a unique-military technology to be implemented with compound semiconductors (GaAs, InP, and other materials). High leverage applications for these are wideband EW and Space Communications. They will also serve as enablers for all digital battlefield reconnaissance systems.**

3. Microwave Technology (0.5 to 200 GHz)
   a. Commercial (0.1 to 5 GHz)
      - COTS use in wireless telecommunications will dominate and provide technology for military use. The exception will be high power, solid-state amplifiers.

   b. Military and Space (5 to 200 GHz)
      - **The progress rate for monolithic ICs will continue only if DoD sponsors an S&T program, to include 6.1, 6.2, 6.3 and MANTECH efforts, of significant size. This program must include efforts to transfer promising R&D results to robust manufacturing processes and systems-ready products. In recent years there have been huge funding cuts in this technology area.**
      - **This microwave technology area is probably one of the three most important electronics enablers for DoD in the early 21st century. Phased array radar, wideband space communications, smart weapon seekers, covert sensors and many new applications for electronic warfare are enabled by this technology.**
      - **With a robust DoD technology program, the rate of progress enjoyed in the 1980s can be extended to higher frequencies, higher integration levels and higher performance levels (power/range, sensitivity, etc.).**

Platform Needs and Trends (21st Century)
Military platforms of smallest size and highest mobility will benefit the most from electronics using unique-military electronics components. These platforms include:

- Manned and unmanned aircraft
- Missiles and smart munition weapons
- UAVs and micro UAVs
- Spacecraft and microsatellites
- 21^{st} century warrior.

Commercial Off-The-Shelf (COTS) Electronic Components
Special Technology Area Review
AGENDA

Thursday, 4 December 1997

PLENARY SESSION

0830-0835	Welcome	CAPT B. Buckley
0835-0900	Overview of STAR Issues and Objectives	W. Howard
0900-0945	DoD Perspective	J. Gansler
0945-1030	Balancing COTS and Security Issues	R. VanAtta
1030-1115	Congressional Perspective	J. Young
1115-1145	Industrial Perspective (R&D Coalition/EIA)	J. Hartman
1145-1215	Just In Time Electronics Systems-DSRC Study Results	T. McGill
1215-1300	LUNCH	

PANELS

1300-1430	Acquisition & SPO Perspective	
	Panel Moderator – R. Bierig	
	Army – ADO	Col. C. Fornecker
	Navy – AEGIS	CDR D. Stevenson
	Air Force – F-22	R. Gibler
	Fleet Logistics Office	N. Riegle
	Joint Strike Fighter	A. Rivera
1445-1630	Defense Systems Industry	
	Panel Moderator – B. Dunbridge	
	Sanders	J. Kreick
	Raytheon	R. Smith
	Boeing	D. Mayfield
	TRW	M. Bever
	Northrop Grumman	W. Eikenberg
	ITT Defense	E. Hammer

Friday, 5 December 1997

0830-1000	Components Suppliers (Military and Commercial)	
	Panel Moderator – T. Hartwick	
	Texas Instruments Military Products	J. Chapman
	Harris Semiconductor	B. Hagerty
	M/A-COM	J. Vaughan
	DELCO	G. Servais
1000-1130	S&T Perspective	
	Panel Moderator – G. M. Borsuk	
	Army	M. Andrews
	Navy	B. Junker
	Air Force	H. Hellwig
	DARPA	N. MacDonald
	California Institute of Technology	T. McGill
	IBM Watson Research Center	M. Polcari
	Lockheed Martin	D. Hutchinson
1130-1230	COTS Insertion Examples – Lessons Learned	
	Army – LONGBOW Radar	K. Richardson
	Navy – ADCAP Torpedo	J. LaCamera
	Air Force – C-17	D. Hartman
	DARPA – Dark Star	D. Lacey

CLOSED SESSION

1230-1315	LUNCH	
1315-1630	Summary, Analysis, Preliminary Findings and Recommendations	COTS STAR PANEL

TERMS OF REFERENCE

COMMERCIAL-OFF-THE-SHELF (COTS) ELECTRONIC COMPONENTS STAR

PRIMARY OBJECTIVE:

The objective of this STAR is to provide information which will allow the Advisory Group on Electron Devices (AGED) to assist the Department of Defense (DoD) in identifying and distinguishing three classes of electronic components for use in DoD systems: (1) those which are available as COTS products and can be effectively used without further R&D investment or logistics support, (2) those components in which modest DoD R&D investment can extend the performance and/or military robustness (i.e. COTS adapted for military purposes), and (3) those custom electronic and electro-optic components which have performance or environmental characteristics that will result in clear advantages for DoD war fighting systems compared to those of our potential adversaries. The components in the latter category are ones that may require DoD R&D investment to allow them to meet the performance challenges of DoD systems required by military mission statements.

The STAR will also examine those factors necessary to create new COTS components, needed by DoD, available in the longer term. The STAR will identify technologies likely to create new COTS in the time period from one to five years in the future as a result of new tools, processes, etc. that are funded as a result of current DoD S&T investment and/or by other sources.

SUPPORTING OBJECTIVES:

1. To establish a concise definition of COTS components.

2. To identify areas where COTS modules and sub-systems can be used without impairing DoD system effectiveness. This set should be updated periodically.

3. To identify areas where use of custom products is essential and a COTS alternative is not expected in the near future.

4. To identify areas where use of modified COTS hardware is most appropriate. For example, enhancing the radiation hardness of commercially available gate arrays, memories, and/or microprocessors.

5. To identify the degree to which battlefield and/or space qualified components and processes differ from commercial sector application components and processes and ascertain the impact of these findings on military parts procurement.

6. To catalog lessons learned from system program managers' prior experience with use of COTS hardware.

7. To assess the impact of COTS use on such issues as logistics, parts replacement, component obsolescence, system maintainability over its lifespan, technology up-dating, packaging technology, performance requirements, power consumption, heat dissipation, environmental constraints, EMP immunity and electrical emissions.

TENTATIVE DEFINITION OF COTS COMPONENTS:

COTS components are those which are either readily available from one or more sources of commercial supply or ones that can be produced using existing design, processes and fabrication capabilities without requiring additional DoD research and development investment.

National Semiconductor has offered four criteria for an IC to be termed "commercial". This includes "military grade" IC's. A commercial IC must meet these criteria:

1. It must be included in a manufacturer's price book or catalog, offered to any potential customer or application

2. A part number that all users recognize must identify it

3. It must be fabricated with a process common to a family of products and assembled and tested using standard methods and equipment

4. It must be interchangeable with all other devices bearing the same part number and (where various grades of product are offered) be downward compatible with all lesser grades of product

QUESTIONS AND ISSUES TO BE ADDRESSED AT THE STAR:

1. What types of electronic functions in DoD systems can make effective use of COTS parts? What are their characteristics and what are the environments in which they operate?

2. How will the use of COTS components affect system reliability and system design? Will commercial (0° - 70°C) and industrial (-40° - +85°C) grade components function reliably in a military (-55° - +125°C) environment? What testing and screening precautions should be taken? Can custom packaging of COTS parts provide electronic components capable of reliable operation under the stress of military environments? Are there new design/manufacturing strategies which can be invoked to make COTS based sub-systems operationally compatible with military functional requirements? What (if any) aspect of the battlefield/space qualified component-development requires specific action by the DoD (including funding support) to assure the availability of these components for DoD weapon system use?

3. Can components/parts meeting very aggressive specifications needed for DoD systems be made in small to moderate volumes with very high yield in facilities which are fundamentally designed and operated to provide very high yield to nominal performance specifications at high rates of throughput? For example, what are the limitations for COTS versions of the following

types of components and how do their specifications compare with DoD system needs? What are the projected cost savings of using COTS components in identified specific application examples as opposed to using custom components or a mix of COTS and custom components? How will the use of COTS impact system life cycle costs?

a) Stable sources (frequency ranges of operation, modulation ranges, short term and long term stability)

b) Microwave and millimeter wave power boosters (amplifiers)--both vacuum tube and solid state types (power levels, operating frequencies, bandwidth transmitter noise characteristics)

c) Receiver/detector (RF and EO) components capable of reliable operation in the presence of jamming and other countermeasures.

d) A/D and D/A converters

e) Components of all types requiring a high degree of radiation hardness

f) Components requiring electromagnetic pulse (EMP) immunity

g) Non-volatile memories

h) Flat panel displays

i) Components intended for use in space

j) Flight qualified system components

4. What techniques can be implemented to achieve extended performance ranges and enhanced reliability characteristics for COTS parts? Would such parts still fit the criteria and be considered COTS?

5. Will the use of COTS hasten the trend toward diminishing manufacturing sources (for military specific components)?

6. How will the use of COTS components affect DoD system logistics? For example, how should anticipated spare parts requirements be addressed? What changes need to be implemented within the present logistics procedures to make the most effective use of COTS?

7. What methods for providing sourcing information about COTS parts to DoD system developers and SPOs are likely to insure parts availability over the operational lifespan of their systems and also provide the anticipated benefits of COTS use such as reduced cost, reduced development time, and enhanced performance?

8. Are there examples of documented savings resulting from the use of COTS components/parts? What were the factors that resulted in those savings? Are they applicable to wider ranges of systems and situations? What was the level of savings achieved? What were the drawbacks of COTS use in those situations, if any?

9. Are models of COTS components adequate to support design of military hardware?

10. How will the use of COTS impact DoD system life cycle costs? If it is necessary to depend upon the use of COTS components in future weapon systems, how will system costs be impacted? Will sufficient component documentation be available to insure maintainability?

11. What will be the impact of the COTS strategy on the technical superiority objectives of the War Fighter Strategy?

12. Is DoD support necessary to assure the continued evolvement of COTS parts for long term technical superiority?

13. What will be the performance consequences for DoD systems should the DoD not be able to fund the development of needed non-COTS components, for next generation systems or system upgrades?

PARTICIPATION:

It is expected that the STAR will provide a forum for discussions between DoD and industrial system program managers, component designers and OEM suppliers. It would be particularly valuable for military technology planners, who define warfighting capabilities, to participate as well as agencies responsible for procurement of major weapons systems and their required logistics support.

ANTICIPATED OUTCOME:

1. A detailed report that describes AGED's recommendations on the use of COTS components in military systems and enumerates both expected benefits and anticipated limitations.

2. A list of DoD needed electronic component types and/or subsystems not amenable to a COTS approach and therefore requiring a DoD investment consideration.

3. Anticipated affordability of non-COTS components.

4. Recommendations on DoD R&D investments in electronics necessary to provide continued military leadership in an international environment dominated by COTS parts in military systems.

QUESTIONS FOR ACQUISITION AND SPO PERSPECTIVES PANEL
COTS STAR
DECEMBER 4-5, 1997
NAVAL RESEARCH LABORATORY
WASHINGTON, DC

1. What is your programs/agency's policy regarding the use of COTS electronic components in military electronic systems upgrades, defense system development procurements and parts acquisition for existing systems?

2. What is your definition of COTS components?

3. What electronic system functions cannot (or should not) be implemented using COTS components?

4. Who makes the "COTS versus Custom" decision, and what are the decision criteria?

5. What are the general lessons learned that are related to COTS component usage from past experience in your agency?

For example in:

- logistics
- parts replacement
- component obsolescence - metrics for forecasting availability?
- system maintainability
- technology upgrading
- packaging
- performance tradeoffs (including power requirements and heat generation)
- environmental tradeoffs if any

QUESTIONS FOR DEFENSE SYSTEMS INDUSTRY PANEL
COTS STAR
DECEMBER 4-5, 1997
NAVAL RESEARCH LABORATORY
WASHINGTON, DC

1. What factors and parameters are taken into consideration in selecting components (either COTS or custom) for systems that you build for DoD? As a contractor, what are the tradeoffs (i.e., risks and rewards) that you assess in deciding between use of COTS and custom components?

2. Which specific systems are ones for which your organization has considered the use of COTS vs. custom component parts? If the systems have been subsequently built, which electronic functions were implemented using COTS and which using custom components? Did system performance meet requirements? If not, what were the causes of the performance shortfalls?

3. In your opinion, is DoD support necessary to assure the continued evolution of COTS parts for long term technical superiority? In your opinion, what will be the performance consequences for DoD systems should the DoD not be able to fund the development of needed non-COTS components, for next generation systems or system upgrades?

4. Which electronic functions in the system(s) your organization has built or is considering building are ones for which COTS parts are considered suitable for implementing? What are the required performance parameters; what environments must the system(s) operate in?

5. Have cost savings through the use of COTS components been documented? If so, will you share information about the magnitude of these savings? What is the anticipated impact of the use of COTS on system life cycle costs?

6. What impact is the use of COTS having on your logistics planning? What approach will your organization adopt to assure that replacement parts will be available for this system 5-20 years in the future?

7. If system(s) built by your organization that use COTS components have already accumulated sufficient field use, is reliability data available. If so, what portions of the system(s) were responsible for generating observed failures, if any?

8. How did the use of COTS electronic components affect system reliability and system design? Did the commercial (0° - 70°C) and industrial (-40° - +85°C) grade components function reliably in a military (-55° - +125°C) environment? Were any special testing and screening precautions taken for any of the components used? Was custom packaging used in an effort to enhance reliability? Were any new design/manufacturing strategies invoked to make COTS based sub-systems operationally compatible with military functional requirements?

9. Are models of COTS components adequate to support design of military hardware? Will sufficient component documentation be available to insure maintainability?

10. In your opinion, what (if any) aspect of the battlefield/space qualified component development requires specific action by the DoD (including funding support) to assure the availability of suitable components for DoD weapon system use?

QUESTIONS FOR COMPONENTS SUPPLIERS PANEL
COTS STAR
DECEMBER 4-5, 1997
NAVAL RESEARCH LABORATORY
WASHINGTON, DC

1. What is your definition of COTS components? What does the term COTS mean to commercial suppliers, military suppliers, and captive suppliers?

2. a. Can the Department of Defense (DoD) develop advanced systems without performing advanced component development and making use of these advanced components?
   b. Will it be possible for the DoD to gain information about advanced commercial component developments, and the products that will result, in sufficient detail to allow the design of systems that incorporate them as these products become available?
   c. Is it likely that commercial suppliers will develop any military unique components without direct funding support and guidance from the DoD?

3. Will technology for COTS components continue to develop at an acceptable rate without continued investment by the DoD in the development of "leading-edge" electronics. What is the history of current COTS products and the expectations for new COTS products that will emerge within the next decade?

QUESTIONS FOR S&T PERSPECTIVE PANEL
COTS STAR
DECEMBER 4-5, 1997
NAVAL RESEARCH LABORATORY
WASHINGTON, DC

1. What areas of S&T will the commercial marketplace dominate? What areas will commercial suppliers make significant investments in over the next 10 years? How can DoD best access this knowledge base for its purposes?

2. What areas of S&T will be the ones that the commercial marketplace will not dominate? What areas, likely to be of considerable importance to the DoD, will commercial sources not make significant investments in? What approach is best for the DoD to pursue in order to perform necessary R&D in areas of crucial importance that the private sector is not motivated to pursue: Use of Government laboratories? Contract R&D with Academia? Contract R&D with Academic-Industrial Consortiums? Contract R&D with defense industry contractors? Other methods?

3. Are the current DoD designations for RDT&E (i.e., Category 6) still relevant today and is the implied model of those designations still valid (i.e., serial transition of knowledge, new capability, and results from basic research to fielded demonstrations)? If not, what alternatives might be more attractive (e.g., S&T investments grouped by time to achieve results)?

4. What are the implications for defense electronics R&D in light of defense industry consolidation?

5. How is the international S&T environment for electronics R&D likely to evolve over the next ten years? What nations/geographical centers will serve as resources for R&D capability? How can the DoD best exploit these capabilities? Are international S&T activities a threat or concern of any kind?

QUESTIONS FOR COTS INSERTION LESSONS LEARNED PANEL
COTS STAR
DECEMBER 4-5, 1997
NAVAL RESEARCH LABORATORY
WASHINGTON, DC

Provide examples of successful and unsuccessful attempts to incorporate COTS components into Department of Defense (DoD) electronics systems? Have there been situations where COTS usage initially looked attractive but turned out to be unfeasible? Why? Are there reverse situations?

Are there system implementation situations (or component areas), that can be identified as general cases, where the use of COTS is the best approach? What are these situations (e.g., computers)?

Are there classes of devices/components that can be identified as being most or least amenable to being as COTS in DoD systems?

In your experience, how often was it possible to make use of COTS components without their modification to meet DoD requirements? If modifications were necessary, how extensive were they?

For systems in which the COTS approach was used, would you recommend its usage now, after the fact? Why or why not?

In retrospect, can you cite examples of systems developed by your organization where a COTS solution should have been used in place of the use of custom components? Are there examples of systems where custom components should have been used rather than COTS?

Appendix AC

STAR Reports

Mixed-Signal Components

REPORT OF
DEPARTMENT OF DEFENSE
ADVISORY GROUP ON ELECTRON DEVICES
WORKING GROUP B (MICROELECTRONICS)

SPECIAL TECHNOLOGY AREA REVIEW

ON

MIXED-SIGNAL COMPONENTS

April 2000

OFFICE OF THE UNDER SECRETARY OF DEFENSE
ACQUISITION AND TECHNOLOGY
WASHINGTON, DC 20301-3140

CLEARED
FOR OPEN PUBLICATION

JULY 18, 2000 7

DIRECTORATE FOR FREEDOM OF INFORMATION
AND SECURITY REVIEW
DEPARTMENT OF DEFENSE

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Prepared by the AGED Secretariat
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1745 Jefferson Davis Highway, Suite 500, Arlington, VA 22202

FOREWORD

Periodically, the Advisory Group on Electron Devices (AGED) conducts Special Technology Area Reviews (STARs) to evaluate the status of an electron device technology or defense application. STARs focus on understanding the military requirements for a particular technology while analyzing the present status of the technology compared to those requirements. The output of the STAR is a report that presents findings and recommendations that are offered to the Office of the Secretary of Defense for strategic planning. To focus each STAR, a "Terms of Reference" document is prepared to describe the purpose, objectives, and issues for the technology focus area.

This STAR report documents the findings from the reviews and assessments of the Mixed-Signal Components STAR, (originally titled *The Future of Silicon-Based Analog Integrated Circuit Components STAR*) that was held in two sessions, on 17 September 1997 and 11 December 1997, by AGED Working Group B (Microelectronics) at Palisades Institute for Research Services, Inc., Arlington, VA. The goal of the STAR was to assess the future military needs for mixed-signal components, the availability and capability of current and emerging mixed-signal components, and to provide recommendations concerning technical directions and investment strategies necessary to ensure that the Department of Defense's (DoD's) future needs are met. Presentations were made by a distinguished panel of experts selected from both industry and government. Working Group B members are subject matter experts in microelectronics technology. The group includes representatives from the Army, Navy, Air Force, National Aeronautical and Space Administration (NASA), Defense Special Weapons Agency (DSWA), National Security Agency (NSA), Department of Energy (DoE), Ballistic Missile Defense Organization (BMDO), and Defense Advanced Research Projects Agency (DARPA), as well as consultants from industry and academia.

On behalf of Working Group B, I would like to take this opportunity to express appreciation for the efforts of the many contributors to this effort, who are listed on the following page. Dr. Susan Turnbach, Office of Director of Defense Research and Engineering/Sensors and Electronics (ODDR&E/S&E), in particular, provided support and encouragement to the project. We thank Dr. Isaac Lagnado, who proposed this topic for a STAR and provided guidance for the STAR's organization. Mr. Ron Bobb of the Air Force Wright Laboratory and Mr. Tim Doyle of Palisades Institute, are particularly thanked and commended for their significant contributions to analyzing the significant amount of data involved in this study and their primary role in producing this report.

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REPORT OF SPECIAL TECHNOLOGY AREA REVIEW ON MIXED-SIGNAL COMPONENTS

EXECUTIVE SUMMARY

The purpose of this STAR was to provide the DoD with recommendations about how to meet future military needs for mixed-signal components. The STAR convened two sessions of expert presentations. The first focused on ascertaining the DoD's need for analog IC components for various applications. The second session brought together a panel of experts to address the ability of current and anticipated designs in meeting the identified needs.

Both sessions clearly revealed that military systems typically contain a higher percentage of analog components than commercial systems. The unique importance of analog ICs to the DoD was particularly apparent as the system requirements for future military systems were outlined. In addition to performance issues for analog components, the availability of these parts, in particular Analog-to-Digital Converters (ADCs), was of great concern.

Detailed examination of data demonstrating the progress in ADCs, showed that, as technology improves, these analog components advance at a very slow rate compared to that of advances in digital circuitry. These devices are challenging to design and produce. There appear to be basic issues yet to be understood to improve their performance.

The business for analog components is modest and focused on commercial requirements for low cost, low speed analog to digital converters. The demand for higher performance analog components for near term system insertion continues, but the sources for these devices are decreasing and the performance is insufficient.

The continued demand for higher performance continues to provide impetus for the development of Gallium Arsenide (GaAs), Indium Phosphide (InP), and Silicon-Germanium (SiGe) technologies for analog components. In particular, the military's need for high bit rates and high speed, stimulate the search for higher performance device parameters to support device performance demands. This interest is also stimulated by the realization that integration alone is not always the most promising approach for increasing system performance and reducing costs. The advances of a higher performance technology in reducing the down-conversion stages involving expensive analog components can offer the best solution for increasing system performance and reducing costs.

Most Government and commercial programs, including research and development efforts, target producing devices that meet the requirements for individual applications. This focus, rather than investigation of the basic challenging technical issues, may be contributing to the limited rate of progress in ADCs. In general, the goal has been on producing prototypes or products rather than understanding underlying technical barriers.

These findings highlighted the importance of basic work needed to understand the current limitations inhibiting progress in ADCs, and the desirability of investments by the DoD to explore and resolve these issues. For the greatest effectiveness in this research, projects should include the entire cycle of development, modeling, analysis, design, fabrication and test.

Considering the magnitude of the cost reductions that specialty (non-Commercial Off the Shelf (COTS)) components can leverage for a system, the value of such components should be examined and measured. The benefits of their use may drive some infrastructure investments by the DoD to accelerate their availability. The limited potential of the military marketplace should be considered and expectations for cost sharing, zero fee, sharing of intellectual property, etc. should be tempered to encourage participation and investment. This is particularly true for the radiation-hardened, low power analog IC market needed for the military's move into space, which is being abandoned by suppliers.

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW ON MIXED-SIGNAL COMPONENTS

INTRODUCTION

Analog ICs are widely used in systems applications where analog interfaces to the external environment are coupled to digital signal processing systems. These include applications in modern telecommunications, consumer products, and automotive electronics. However, DoD systems, in particular, utilize large numbers of analog ICs with high performance and reliability demands. These are used to couple critical military sensor data with signal processing so that information can be analyzed and utilized. The juncture between the analog and digital worlds can be problematic. This is especially true for: (1) the high frequency, low noise, low voltage, and low power regions in which portable telecommunications and computational devices are designed to operate, and (2) the high voltage and radiation-tolerant circuitry required by the military.

Several issues exist for matching sensor-to-sensor interface circuits to achieve high performance and reliability. Although the integration of sensor interface circuits and digital control logic has been successful in a few cases (notably for temperature, pressure, and chemical sensing), integration is usually associated with serious difficulties. In "smart sensor systems," the electronics incorporated in sensors reduces and alleviates these deficiencies. However, designing sensor interfaces for broad multipurpose applications continues to be a major challenge.

The technical realities of the analog IC area, in conjunction with the economic and business considerations governing that area, suggest two issues. One, that continuing research and development investment is needed to produce devices that meet the needed performance requirements. And second, that an infrastructure that supplies critical military and commercial products is basic to ensuring technological leadership on the battlefield and in the marketplace.

The STAR investigated military needs for analog ICs on three levels:

- Devices – analog IC functions common to a variety of applications
- Applications – specific analog IC devices critical to communications, radar, electronic warfare and missile control applications
- Infrastructure – aspects of the life-cycle management of analog IC devices in systems including computer-aided design requirements, radiation hardness needs, parts obsolescence issues, and provisions to improve and streamline system maintenance.

Correlating with the drive in the commercial sector to develop digital solutions for analog functions, ADCs were the principal focus of concern for the experts who presented information to the study. In fact, three of the seventeen presentations

specifically focused on ADC technologies, and in the presentations by the other speakers, ADCs were prominently addressed. Current state of the art digital processing capabilities do not support operation at radio frequencies. Therefore, the ADC must down-convert signals from radio frequencies to speeds at which the signals can be digitally processed. Present efforts to improve ADCs are centered on ways to reduce the number of links in the chain of analog down-conversions.

TECHNOLOGY BACKGROUND

Traditionally, IC devices have been broadly classified as either analog or digital. That is to say, they are designed to operate with either continuously or discretely varying electromagnetic signals. Different functions naturally lend themselves to one or the other of these two types. However, digital signals offer a distinct advantage in their ability to withstand distortions due to the noise and interference inherent to the propagation paths through which all electromagnetic signals must pass. Because of this advantage, considerable effort has been expended to develop "digital solutions" to situations that, in the absence of noise and interference, are more naturally analog in character. Conventional wisdom now understands "digital" to be synonymous with "better" and defines advances in electronic technologies as the replacement of analog products with digital ones.

There are, however, natural limits to the types of functions for which digital solutions can be applied. The propagation of Electromagnetic (EM) waves through the atmosphere (e.g. radio, television, cellular telephones and radar) depends on creating EM fields whose strengths vary continuously with time. In most applications, these EM waves are necessarily transmitted at frequencies that exceed state-of-the-art digital processing capabilities. In these situations, analog ICs fulfill the critical role of coupling radio frequency signals with digital processing circuits.

Today, most organizations (private companies, government agencies, academic institutions, etc.) pass the majority of their electronically encoded information among individuals located within a collection of buildings. In contrast, military units typically pass EM data among a variety of environments, systems and platforms. Many of these platforms cannot afford in their operation to have their freedom of motion limited by an umbilical "wire." Military applications, in a relative sense, are more heavily dependent on analog ICs than commercial systems. Table 1 below gives some indication:

System	% Analog ICs of Total IC Count
Trident	43
MM-III GRP	69
GPS IIR	20
THADD	24
EKV	47

Table 1 – Analog Percentage of Total IC Count for a Sample of Military Systems

SOURCE: Mr. David Emily, Presentation to AGED Working Group B (Sept. 17, 1997)

Interpretation of these figures is difficult because of the different natures of analog and digital ICs. To be fair, advances in the ability to reduce the feature size of elements on an IC (e.g., the number of transistors per sq. cm.) have been more successful

and rapid for digital applications. Therefore, one would expect the digital percentage of the total IC count to decrease with each system generation and a consequential rise in the analog portion. However, the causes aside, it is still clear from the data that the need for analog ICs to implement system functions are significant

Given the commercial sector drive to develop digital solutions for analog functions and in the wake of changes to DoD procurement procedures, this study has focused on anticipated military needs for analog ICs and the approaches and mechanisms for fulfilling these requirements.

SESSION ONE PRESENTATION SUMMARIES
Military Needs for Mixed-Signal Components

DR. ROBERT WALDEN – HUGHES RESEARCH LABORATORIES
ANALOG-TO-DIGITAL CONVERTERS: SURVEY AND ANALYSIS

Dr. Robert Walden gave two presentations at the STAR. His first presentation was a short tutorial on ADCs. The tutorial covered basic definitions of the more common terms used when describing an ADC. He also introduced a Performance term, $P = 2^{SNRbits} \times f_{samp}$ and from this established an ADC figure of merit, F = Performance/power dissipation. Dr. Walden has accumulated data on more than 150 converters and plotted these ADCs vs. their figure of merit. Dr. Walden also presented his now famous graphs of Signal to Noise Ratio (SNR) bits vs. Sample Rate and Spur Free Dynamic Range (SFDR) bits vs. Sample Rate, as shown in Figures 1 and 2.

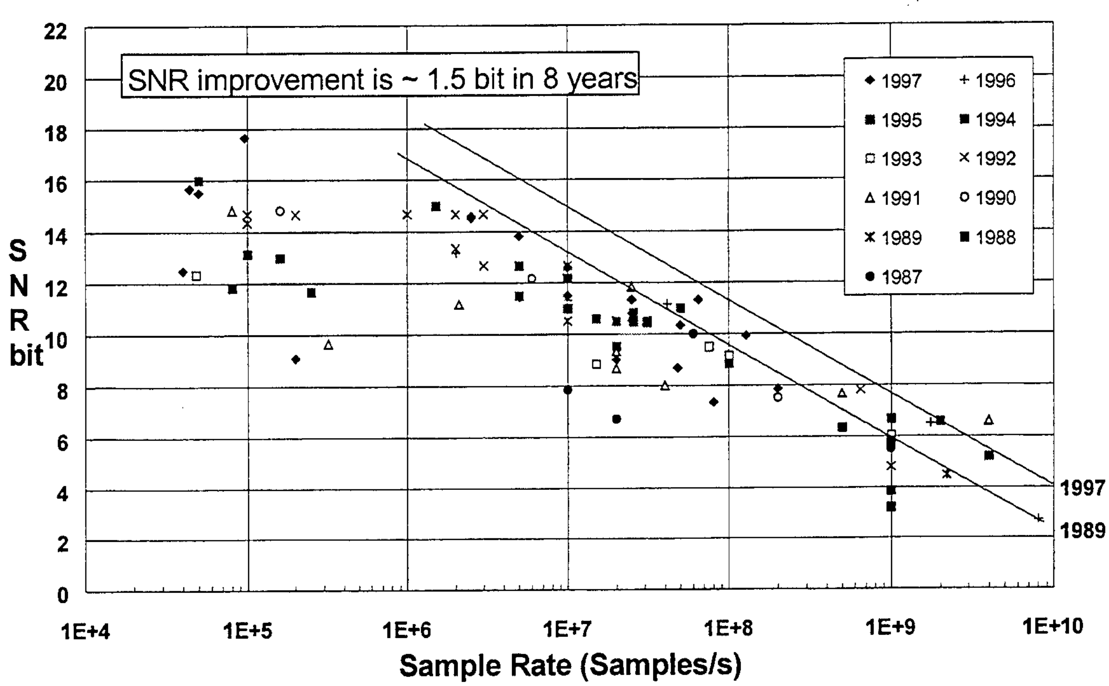

Figure 1 – SNR Bits vs. Sample Rate

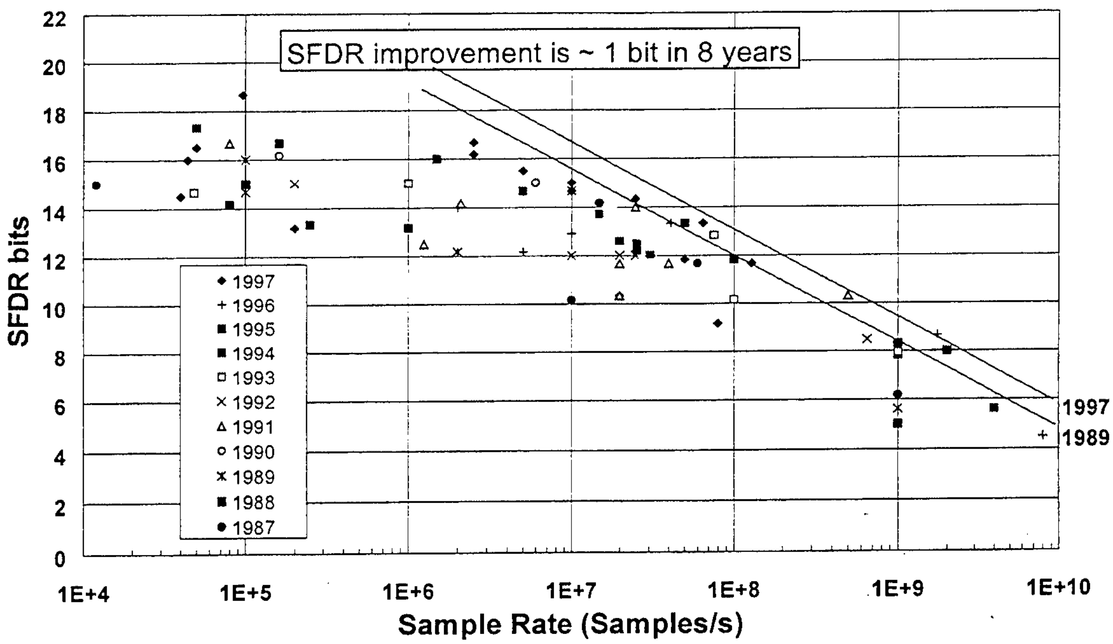

Figure 2 – SFDR Bits vs. Sample Rate

The updated charts used by Dr. Walden show that SFDR improvement is ≈ 1 bit in 8 years and SNR improvement is ≈ 1.5 bits in 8 years. It was suggested that slow improvement in ADC performance in recent years can be attributed to 1) de-emphasis in R&D, 2) fundamental limitations of individual technologies (thermal noise, regeneration time constant, aperture jitter, etc.), and 3) lack of a large commercial pull for the type of high performance ADCs needed for military applications. (This was also made obvious by Dr. Buss' subsequent presentation.) Conclusions drawn from this portion of Dr. Walden's presentation were that the fundamental ADC limitations need to be thoroughly studied and understood and the Government needs to continue investing in this area of work if significant progress is going to be made in performance regimes of interest.

Dr. Walden's second presentation covered Communications for Dr. Michael Delaney from Hughes Space and Communications Government Electronics Business Unit. This talk contained proprietary data that cannot be included in detail in this document. However, a number of salient points can be noted. Among the issues for this application, were: Plastic Encapsulated Microcircuit (PEM) vs. hermetic packaging; new materials needed for analog IC packages; lack of space qualified analog ICs; commercial parts meeting all requirements; and, a strong need for analog Monolithic Microwave Integrated Circuits (MMICs) and Microwave Integrated Circuits (MICs) which span the frequency range from C to W-band. The types of parts that are needed include Low Noise Amplifiers (LNAs), Phase Locked Loops (PLLs), mixers, mixed-mode Application Specific Integrated Circuit (ASICs), analog components for power supplies, and Direct Digital Synthesizer (DDS) chips. Again the main point of this presentation was that there is a need for a wide range of analog ICs for communications which are presently beyond

commercial state-of-the-art, mandating continued development activities in high speed technologies like SiGe and III-Vs.

MR. BRIAN WONG - TRW
ANALOG-TO-DIGITAL CONVERTERS FOR FUTURE MILITARY SYSTEMS

Mr. Brian Wong presented TRW's view regarding requirements for digital receivers for military applications. This is encapsulated in Table 2, below. The traditional desire is to move the ADC closer to the antenna/sensor in order to maximize the digital content of the receiver, thereby reducing the size, weight, power and cost while increasing the receiver's flexibility. While much of the digital circuitry following the ADC can leverage the considerable commercial Complementary Metal Oxide Semiconductor (CMOS) investments, the requirements for military ADCs far exceed their available commercial counterparts.

MISSION	SAMPLE RATE (Bandwidth)	SNR/SFDR (Effective # of Bits, ENOB)	POTENTIAL AVAILABILITY FOR ADC
COMM	250 MSPS (100 MHz)	85 dB / 100 dB 14 ENOB	5 to 10 Years 16-bit / 250 MSPS
RADAR	100 MSPS (>20 MHz)	75 dB / 85 dB 12 ENOB	3 to 5 Years 14-bit / 100 MSPS
EW/ESM	3 GSPS (1 GHz)	56 dB / 65 dB 9 ENOB	5 to 10 Years 10-bit / 3 GSPS

Table 2 – Requirements for Military ADCs

TRW has selected III-V Heterojunction Bipolar Transistor (HBT) technology as the technology of choice to meet these stressing ADC requirements. They have been developing ADCs and ADC components in both GaAs and InP for a number of years. These developments have been primarily funded by the Government due to the limited commercial pull for these high performance components. With continued DoD investment in technology for ADCs, the following prediction is made by TRW:

	0 to 5 Years	5 to 10 Years	10 to 15 Years
High Resolution ADC	12-bit / 160 MSPS	16-bit / 250 MSPS	16-bit / 500 MSPS 18-bit / 250 MSPS
Wideband ADC	9-bit / 3 GSPS 10-bit / 1 GSPS	10-bit / 3 GSPS	10-bit / 8 GSPS

Table 3 – Predicted Availability for High Performance ADCs

As indicated in the two tables above, no single ADC will meet all the requirements demanded for the military. The high resolution ADCs will more than likely be fabricated in advanced CMOS, thus leveraging the commercial pull for this technology. These ADCs will meet the requirements for Communications and Radar as stated above. However, the wideband ADCs needed for Electronic Warfare (EW)/ Electronic Signal Measurement (ESM) do not have a commercial pull. To foster the development of these high performance ADCs, continued Government funding in device technology and analog design will be needed.

MR. ANTHONY SPEZIO – NAVAL RESEARCH LABORATORY (NRL)
ANALOG ELECTRONIC SIGNAL PROCESSING

Mr. Anthony Spezio started his presentation by identifying the domain of analog signal processing in today's military systems. Analog processing has some significant advantages over current state-of-the-art digital signal processing. Analog processing also has well-known disadvantages which have been cited by many. These include inflexible algorithms (not programmable), susceptibility to noise and temperature and cost.
Mr. Spezio showed the following figure that depicts the ideal sensor system provided that ADC and digital technologies meet the targeted requirements.

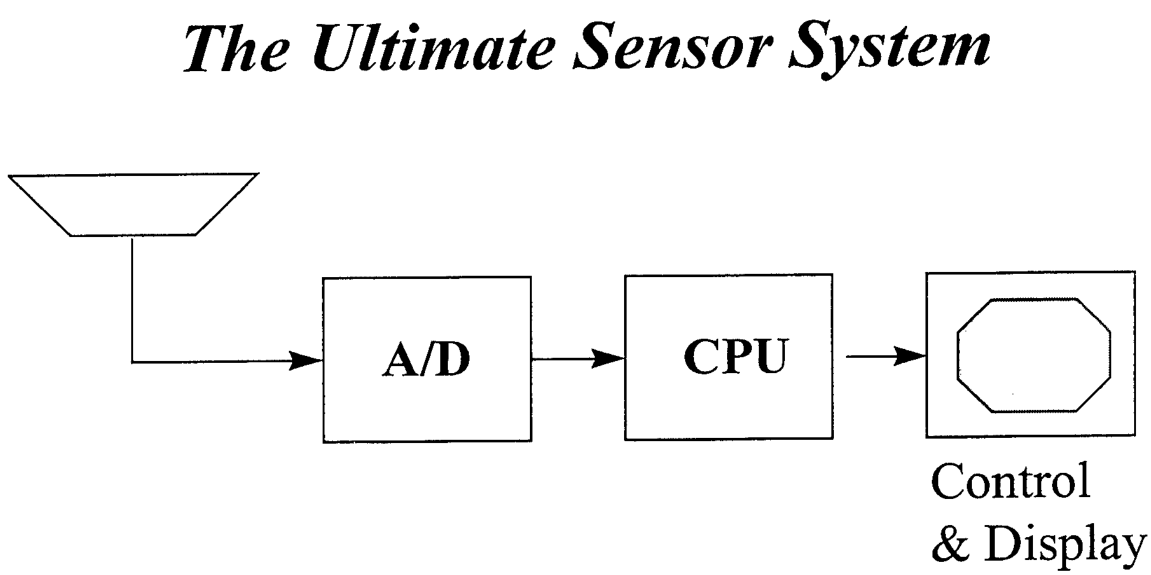

Figure 3 – Ultimate Sensor System

The analog signal is converted directly to a digital one at the antenna, thus, no analog amplifiers, downconverters, mixers, etc. are required.

Unfortunately, current ADC and digital technologies are not yet at this point. The following Digital Signal Processing (DSP) shortfalls were noted: 1) wide bandwidth, high

resolution signal conditioning and digital conversion; 2) parallel channel simultaneous signal conditioning; and, 3) high computational capacity transforms and algorithms.

Mr. Spezio went on to define the EW environment, functional requirements and the signal processing space for the EW efforts in which he is involved in at NRL. This is captured in the following table.

EW Environment		
Observable Emitters From Ship From Aircraft	 100 2000	
Environment Density	$> 10^8$	
Copulse Probability	≈ 100%	
Functional Requirements		
	Warning	**Surveillance**
Time to Classify	2 sec	60 sec
Time for SEI Sort	10 sec	120 sec
Time to ID		300 sec
Time to Unambiguous Bearing	2 sec	120 sec
Time to Locate		300 sec
Revisit	2 sec	300 sec
Signal Processing Space		
Feature	**Characteristic**	
	Current	Projected
Operating Frequency	0.5 to 20 GHz	0.1 to 100 GHz
Frequency Resolution	100 kHz	1.0 kHz
Spatial FOV	2 PI steradians	2 PI steradians
Bearing Resolution	10^{-6} steradians	10^{-8} steradians
Time Resolution	10 nsec	0.1 nsec
Signal Event Duration	100 nsec	1.0 nsec

Table 4 – EW Environment and Requirements

Mr. Spezio gave several examples of analog signal processing by citing several receiver modules and individual components that have been developed or are underway at NRL. The conclusions drawn from his presentation are as follows: 1) analog signal processing will continue to be a necessary system technology; 2) integrated analog signal conditioning and digital conversion are required; and, 3) multichannel analog and digital are necessary for timely results.

Mr. Todd Kastle – Air Force Wright Laboratory
Radar Requirements for Analog Integrated Circuits

Mr. Todd Kastle presented an overview of airborne radar requirements for a notional fighter. The technology drivers for this radar are:

Apertures
- Wideband
- Observability
- Modules

Receivers - Channelized/Superhet
- MMICs
  - LNAs, Mixers, Filters
- A/D Converters
- Filters
- Digital Signal Processing
- Channel Match (Channel to Channel)

Direct Digital Synthesis

Narrowband/Wideband
- D/A Converters
- High Speed Waveform Generator
- Phase Compensation
- Filters

Processing
- Flexibility
- Degrees of Freedom
- Interference Reduction Effectiveness

Waveforms
- Algorithm Software Capability

Design Tools
- Utility
- Trade Space Capability
- Fidelity
- Accuracy

Systems Analysis
- Threat Analysis/Projection
- ConOps
- Tactical System Design

The briefing covered a wide range of material from basic definitions of commonly used terms, to mission scenarios, to a brief explanation of the trade space used for requirements flow down vs. performance parameters. One of the key points of this presentation was that multimode tactical airborne radar presents ADC designers and manufacturers with some very difficult requirements. Some of these requirements are as follows:

Mode	HRM*	MPRF/RGHPRF**	HPRF***
Signal Bandwidth (BW)	60 MHz 600 MHz (Growth)	5-10 MHz	1 MHz
SNR	34 dB	75 dB	90 dB
ENOB	5.5	12.5	15
SFDR	53 dBsat	96 dBsat	117 dBsat

Table 5 – Requirements for Multimode Tactical Airborne Radar Modes:

* High Resolution Mode (HRM)
** Medium Pulse Repetition Frequency (MPRF)/Pulse Repetition Frequency (RGHPRF)
*** High Pulse Repetition Frequency (HPRF).

The trend to push the digital interface closer to the antenna/sensor as evidenced in the presented receiver technology roadmap will continue to challenge ADC suppliers. Mr. Kastle concluded his presentation with the following table of radar requirements:

	Multi-Mode Strike	**A/G Surveillance & Weapon Delivery**
RF Operating Bandwidth	L to X-band 200 MHz to > 4 GHz BW	X to KU-band 200 MHz to > 4 GHz BW
IF BW	50 MHz typical, mode selectable	> 50 MHz
Dynamic Range (Spur Free)	45-75 dB (mode specific)	45 to > 60 dB (mode specific)
A/D Bits (Effective)	12-16 bits (mode specific)	8-12 bits (mode specific)
# of Receive Channels	2-8 typical	1-2 typical
Stability (typical)	-95 dBc/Hz	-70 dBc/Hz
Linear FM BW	10-30 MHz	100-600 MHz or more

Table 6 – Requirements for Radar

MR. DAVID EMILY – NAVAL SURFACE WARFARE CENTER – CRANE
RADIATION-HARDENED ELECTRONICS REVIEW

Mr. David Emily gave a presentation on radiation hardened analog components, in particular, describing Crane's experience in working with commercial manufacturers and radiation hardening for their processes. Since the market for these specialty components is so small, manufacturers are reluctant to consider process modifications, making screening the alternative for obtaining rad-hard devices. The CMOS analog components exhibit greater sensitivity to exposure. Although he predicted the ratio would shift in the future, he described military systems as currently having large fractions of analog compared to digital components.

He described some of the challenges in defining an effective screen, and that analog is intrinsically soft compared to digital. The higher voltages make analog circuits more susceptible to dose rate and latchup problems. He described an enhanced low dose rate sensitivity phenomena affecting bipolar devices, especially circuits containing commercial type lateral PNP elements, where circuits may fail at 1/10 or less than the expected level. Applications such as satellite systems are particularly vulnerable to these issues. However, since the total volume for that market is quite small, it is not a major driver for investment.

The most common approach to this risk for satellites, is using conservative design margins, and special screening. This adds a significant premium to the parts cost. For strategic hardness levels, however, the situation is much more problematic since components produced for the commercial market are unlikely to meet the requirements.

He estimated that there are only two real suppliers remaining, down from six, for rad-hard devices. He saw divergence between commercial and military requirements in the operating voltage, which is higher for more demanding performance. He predicted that bipolar and bipolar-Silicon on Insulator (SOI) would continue to dominate.

Mr. Emily's recommendations for the DoD in this scenario included:

- Assess commercial processes
- Leverage commercial processes
- Develop analog electronic design analysis (EDA)
- Improve process modeling
- Assess emerging technologies
- Consider SOI starting material

MR. MAJOR FECTEAU – REDSTONE ARSENAL
ANALOG INTEGRATED CIRCUITS FOR NEXT GENERATION TEST EQUIPMENT

Mr. Fecteau presented the Army's approach to General Purpose Test, Measurement and Diagnostic Equipment (GP-TMDE). Their focus is on embedded diagnostics, in particular, on-chip diagnostics that are able to display data or diagnostic information eliminating the need for external test equipment.

He showed a challenging example – the modern day warrior with headmounted audio/visual system, central processor, battery pack, best-mounted electronics and radio frequency (RF) communications. The types of analog ICs cited as needed, all at low cost, include:

- "intelligent" analog ICs, including ADCs with data logger capability
- MMICs
- thermal micro-sources
- temperature, humidity, pressure (including altitude), shock/vibration sensors

MR. KEITH MEYER – TRACOR ENGINEERING SYSTEMS
AFTERMARKET SUPPORT CAPABILITIES FOR ANALOG INTEGRATED CIRCUITS

Mr. Meyer noted that historically, the analog market has been more stable than the digital market. However, despite this usual scenario of a steady and profitable business, the presence of analog devices is shrinking in the overall IC market. Of the top ten analog IC manufacturers, only three address military requirements. The growing consumer and telecommunications market has captured the attention of the analog suppliers.

The multi-faceted approach followed by his organization includes:

- Purchase discontinued product lines from aftermarket suppliers
- Purchase die from original equipment manufacturer (OEM) and perform custom assembly
- Reverse engineer needed devices
- Substitute pin-pin replacements or functional equivalent, or attempt to up screen.

DR. ROBERT EWING – AIR FORCE INSTITUTE OF TECHNOLOGY (AFIT)
THE CHALLENGES & SOLUTIONS TO ANALOG DESIGN

Professor Robert Ewing presented an overview of the current status of Computer Aided Design (CAD) tools available for analog circuit design. His briefing pointed out that today's analog CAD tools have severe limitations. Current tools lack accurate high frequency models, are application dependent, very slow, inaccurate for submicron regimes and are not integrated in a framework. Current tools also lack a common data structure. This prohibits the tools from interacting and also impedes connecting behavioral and structural simulation tools. Many of these problems are compounded with the emergence of MicroElectroMechanical Systems (MEMS) technology. The concept of "Mechatronics" (Figure 4) was introduced as a new engineering discipline in which the entire system is considered in terms of modeling.

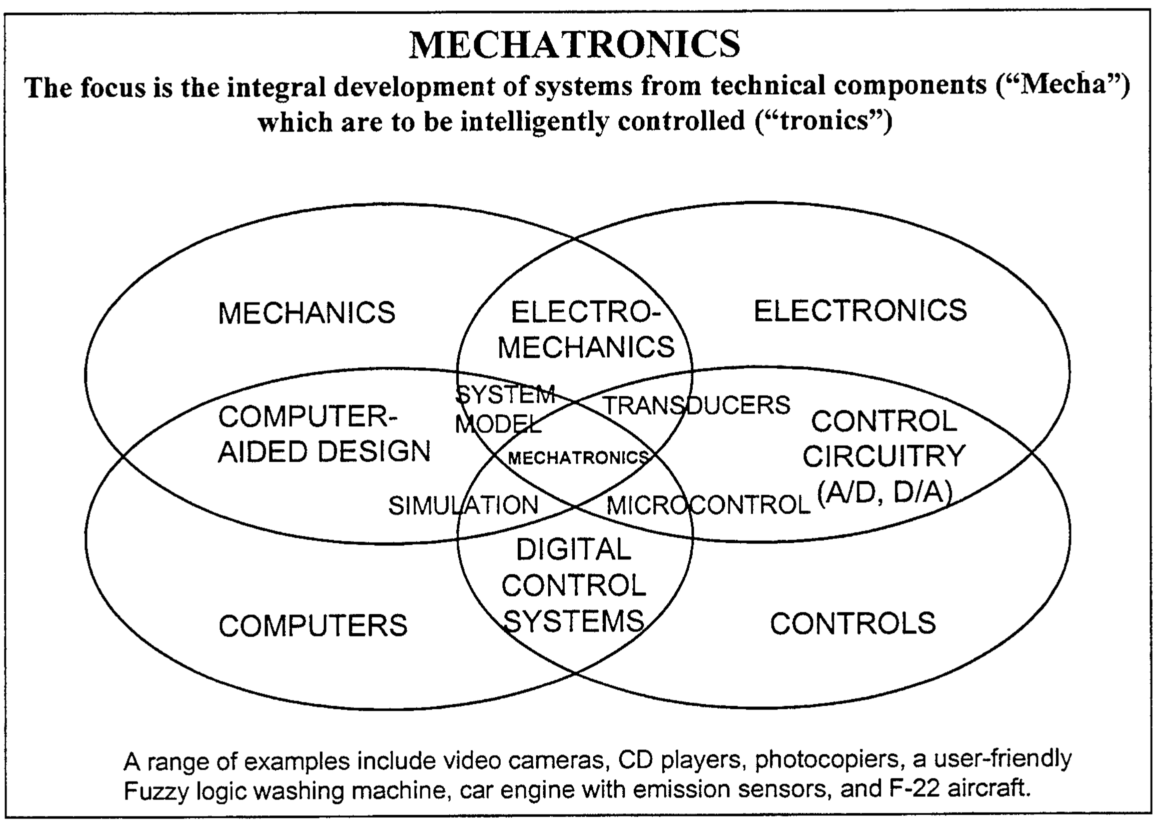

Figure 4 – Mechatronics – Modeling of Entire System

During the briefing a framework structure for analog/digital design was proposed which will enable multiple CAD tools (behavior/structural/simulation/synthesis) to analyze the state equation Matrix for simulation and synthesis applications. This is the same Matrix form used by SPICE and is accessible within Wright Lab and AFIT's version of SPICE called TOTAL. The idea is then to develop tools around this Matrix form. Both VHSIC Hardware Description Language (VHDL) and VHDL-Analog Mixed Signal (VHDL-AMS) would be parsed into the SPICE Matrix form. It was suggested that an industry standard analog library designed around an operational amplifier parameterized model be included as part of this analog CAD package. Within this proposed framework, device scaling issues will be handled with Dimensional Analysis and transistor matching issues will be solved with Quantitative Feedback Theory (QFT). As a starting point for robust analog designs, a proposed ideal educational oriented CAD package combination would be ACACIA from Carnegie Mellon University and the TOTAL package from AFIT and Wright Laboratory.

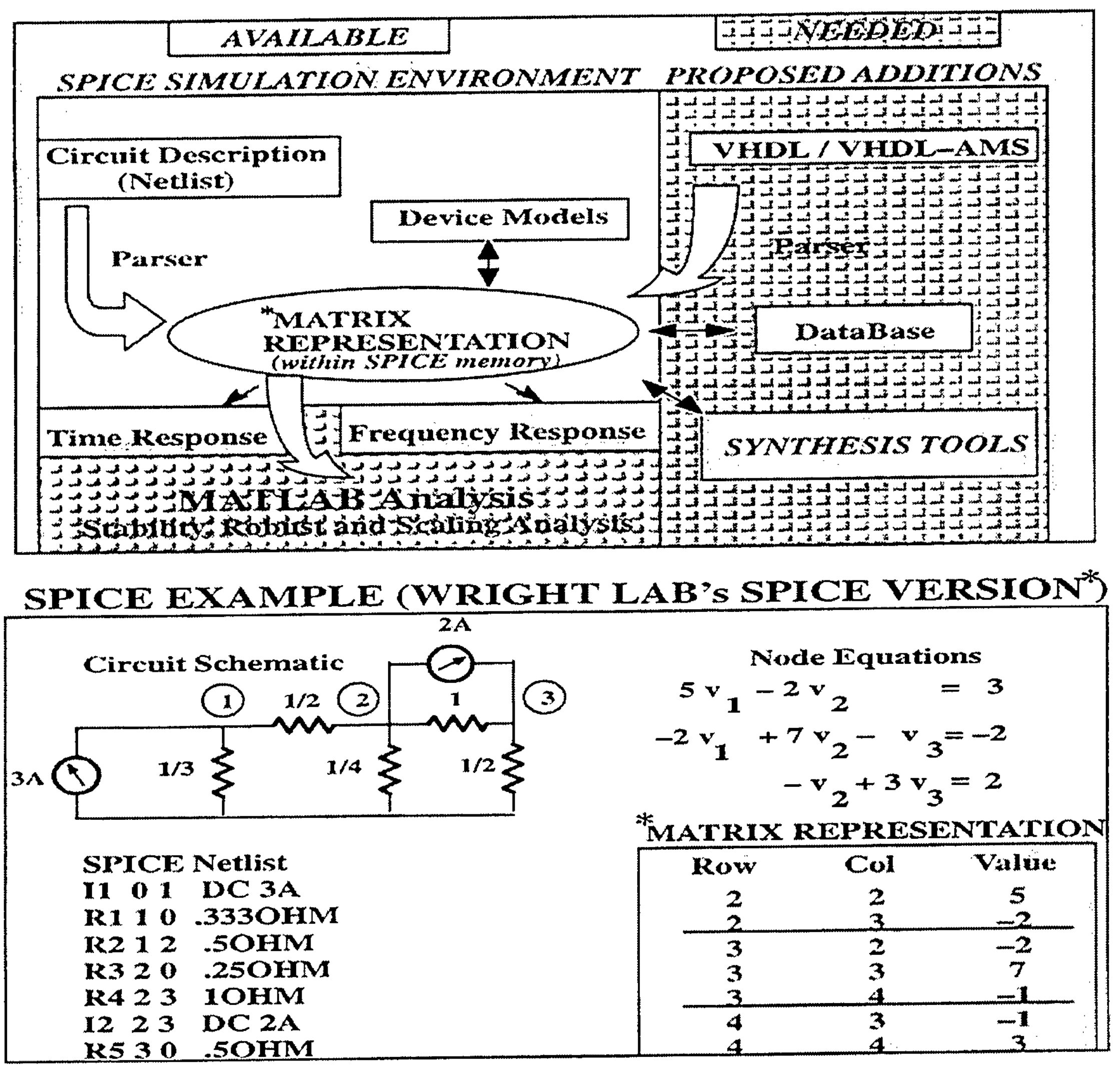

Figure 5 – Framework for Analog/Digital Design

Reference: Dr. Ewing distributed at the STAR

MR. J. P. LETELLIER – NAVAL RESEARCH LABORATORY
RADAR NEEDS FOR ANALOG DEVICES

Mr. J. P. Letellier gave a presentation for Dr. Ben Cantrell on Future Surveillance Radar. The objective of this effort is to develop concepts and technologies for a new large power-aperture, cost-effective, shipboard volume surveillance radar. This radar has a potential 10-year market of 250,000 L-band units, 1,000,000 X-band units and 400,000 S-band units. For such a large volume of units, cost is obviously a prime consideration. Three specific analog components along with their required specs were identified for this radar. These components are listed in the table below:

DEVICE	REQUIREMENTS
Solid State Power Amplifier	• high gain : 30 dB in single MMIC chip • 25% bandwidth • UHF (250W), L(100W), S(75W), X(20W) • low phase noise: -130 dBc/Hz/per Amp • low cost: $100 each
MMIC Receivers	• monolithic; up to triple conversion • external filter connections • large dynamic range: >100 dB in, >80 dB out • low noise
A/D Converters	• >100 MHz analog input • >90 dB dynamic range

Table 7 – Analog Components with Required Specifications

The presentation also covered new technology investigations for Transmit/Receive (T/R) modules for the Future Surveillance Radar (FSR). A brief discussion on Δ-Σ data conversion techniques was given and how these techniques can be applied to both the ADC and Digital-To-Analog Converter (DAC) functions of the T/R modules. Several configurations for the T/R module were given from all digital to increasing analog content. The configuration of choice will depend on the availability of digital parts and their associated costs. In the case of Option 3 where dual up/down conversion techniques are used, the ADC requirement (14 bit, 65 MHz) could be met with COTS parts in the near future. However, on the same chart that depicts the block diagram for the dual up-/down-conversion, a 17 bit ADC was preferred. If the same output data rate is desired, this is clearly beyond what is available or soon to be available from the commercial market.

Another area where new technology is being considered is the power amplifier. Currently available COTS amplifiers have low gain and as a result, several have to be ganged together to achieve the necessary gain. The preferred approach is to use a single high gain amplifier. Low yield and high costs are current barriers to this approach.

DR. DENNIS BUSS – ANALOG DEVICES
TRENDS IN COMMERCIAL ANALOG-TO-DIGITAL CONVERTER TECHNOLOGY

Dr. Dennis Buss' presentation was probably better suited to the second session, rather than the first session of the STAR. His briefing did not identify analog component requirements, but rather, the chips that were available from his company. As the title of his briefing suggested, his approach to meeting the DoD's stressing analog component requirements is to use COTS parts.

The DoD is no longer the dominant volume market for high speed ADCs. Communications and consumer electronics now drive the market for advanced ADCs at Analog Devices. The requirements for these applications can be met with commercial silicon processes, either bipolar or CMOS, in many cases. Dr. Buss' recommendation was that if the DoD has requirements that can not be met by their current line of products, then change the architecture so that needs can be met with one of Analog Devices' products. Members of the audience recognized that for a shipboard application, for example, it may be possible to channelize receivers and use their COTS ADCs. However, when there are size and weight constraints, e.g., as in missiles, satellites and tactical aircraft, this approach is not always practical.

The remainder of the briefing went on to discuss trends in commercial technologies. One key point that came out of this part of the talk was the fact that voltage scaling will complicate SNR limited designs. For analog circuits at the SNR limit, a lower supply voltage will actually result in an increase in power.

MR. RAYMOND IRWIN – ARMY NIGHT VISION LABORATORY
ELECTRONIC WARFARE ANALOG INTEGRATED CIRCUIT REQUIREMENTS

Mr. Raymond Irwin from the Army's Night Vision Lab provided material for the EW area that highlighted the following analog needs:

- RF Jammer Transmitters
  - Solid state devices that support many octaves of bandwidth and several hundred watts of Continuous Wave (CW) output power for High Frequency (HF) (2-30 MHz),Very High Frequency (VHF) (30-100 MHz), and Ultra High Frequency (UHF) (100-1000 MHz).
  - Microwave Power Modules (MPMs) consisting of a solid state front end with approximately 30 to 40 dB gain followed by a CW Traveling Wave Tube (TWT) with 30 dB of gain with a built-in power supply. The microwave bands of interest are 2-6 GHz and 6-18 GHz. Typical millimeter wave bands are 30-40 GHz for EW and 42-45 GHz for Satellite Communications (SATCOM).

- Microwave and Millimeter Wave Power Module Components
  - Switching transistors for power supply.
  - Drivers, solid state devices in the bands of 2-6, 6-18 ,18-40, and 40-45 GHz. The trend is for solid state devices to produce approximately 0.25 watts CW and have TWTs amplify to the 50 to 100 watts level.
- InfraRed (IR) Missile Warning: IR Focal Plane Arrays (** This is probably outside the scope of this STAR **)
  - 256 X 256.
  - Multi-color operation: Several detection bands in 3 to 5 microns.
  - Operation at high temperatures: Thermoelectric (TE) cooled (no cooling the goal).
- Synthesizers for receiver Local Oscillators (LOs) and transmitter exciters
  - Octave or better tuning.
  - Tune in less than 1 μsec.
  - Bands: A through M.
  - Typically placed in SEM-E plug-in modules for aircraft and custom modules for ground vehicles (RF standard for ground vehicle not established).

SESSION TWO PRESENTATION SUMMARIES
Investment Strategies for Mixed-Signal Components

MR. CHARLES TABBERT – HARRIS SEMICONDUCTOR
RADIATION-HARDENED ANALOG TECHNOLOGY DEVELOPMENTS

Mr. Tabbert presented the supplier and the user perspective, from his background managing component engineering on Global Positioning Satellite (GPS) and MILSTAR. He presented a number of proprietary charts outlining Harris' strategy for supplying military components while effectively leveraging and pursuing the commercial market. He cited a need to dial-in the hardness required for a particular application, through both processing and design.

He noted that Low Earth Orbit (LEO) commercial satellite builders are more aggressive than military designers in defining specifications. He defined the current process with a feature size at 0.6 micron and bonded wafers, which are also used in commercial technologies. He noted the importance of the design tools that must be supported, as well as the process. Harris has worked with its major customers in a Design Center format, and offers a number of different processes with variations to serve its targeted market segments.

Mr. Tabbert noted that while the DoD cannot direct the marketplace as in the past, it can steer interested manufacturers through its spending. He also commented that the real issue for systems is parts obsolescence rather than process obsolescence. He recommended timely DoD investments in design automation and enhanced CMOS processing.

MR. THOMAS "STONY" EDWARDS – NATIONAL SEMICONDUCTOR (NSC)
FUTURE OF SILICON-BASED ANALOG INTEGRATED CIRCUIT COMPONENTS

In FY97, NSC received six percent of their revenue from Mil/Aero, the largest portion of any semiconductor supplier. Also, NSC is currently operating five fabs, (previously seven), and two assembly locations (previously seven). The NSC corporate strategy is to offer "systems on a chip" leveraging analog technology for key, trend setting customers with a short (six month) time to market. They are consolidating multiple technologies into a few and further merging these into single designs. A similar approach is proposed for military business.

Unique military challenges include temperature range, life cycle, Diminishing Manufacturing Sources (DMS), performance, radiation and need for "special" product and technology development. Common commercial and military needs are communications, security, mobile applications, and low cost.

The NSC views Very Large Scale Integration (VLSI) Mixed Signal Design on CMOS, High Speed (>1 GHz) Circuits, and High Density Processing as key areas for investment. Their proposed working solutions are: cost-shared research and development (R&D), mil-temp capable core technologies, development of "dual-use" packages, development of leading edge analog/mixed-signal design and simulation tools, buying of Mil parts to sustain infrastructure and promoting dual-use technology funding.

NSC's Mil/Aero Strategy is to bring the latest technology to their DoD customers. This will be done by tying similar DoD and Commercial needs together, in the areas of Telecommunications, Computing, and Systems-on-a-Chip. This involves co-funding innovative technologies with multiple markets, including, process/manufacturing technology, rad-tolerant process development, Low Temperature Cofired Ceramic (LTCC) Wireless and Adaptive Computing.

MR. BRAD LITTLE – TEXAS INSTRUMENTS
TEXAS INSTRUMENTS' FUTURE PLANS FOR MIXED SIGNAL INTEGRATED CIRCUITS

Mr. Little presented an overview of the military mixed signal offerings from Texas Instruments, and illustrated the product life cycle of a mixed signal circuit. For operational amplifiers for example, these included Bipolar Field Effect Transistor (BIFET), CMOS and bipolar circuits. He noted that the military life cycle may be extended compared to the commercial life cycle, depending on the volume and program commitments.

He showed a chart (Figure 6) of where Texas Instruments' views the applications for ADCs of various performance levels.

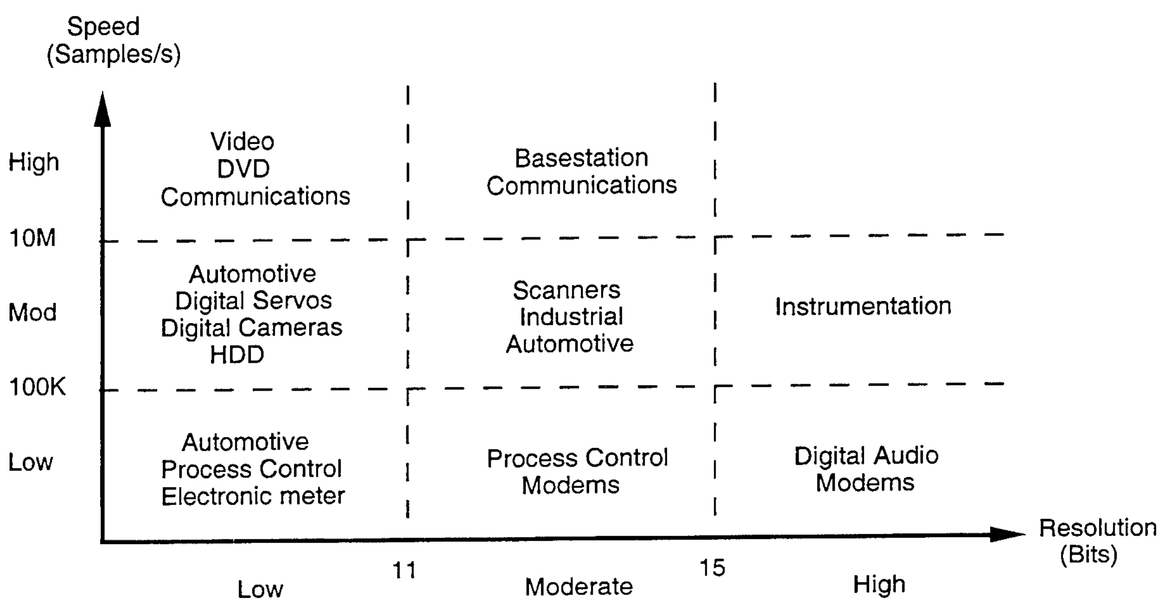

Figure 6 – Applications for Performance ADCs

Dr. Henry Chang - Cadence
Mixed Signal Design in System-On-A-Chip Transition

Dr. Henry Chang began by showing the market drivers for mixed signal chips, including the applications, the levels of integration, and product design cycles. He forecast the transition to systems-on-a-chip, moving from the ASIC, to complex ASICs with a few Inputs-Outputs (IOs), to plug and play systems on chip. He also illustrated the phases of the mixed signal transition and the primary features and players in making this happen.

He predicted that, in the future, design would be top down, with constraints added at each level as applicable. This will offer the benefits of a systematic design approach which documents and implements the trade-offs made at each stage of the design cycle as well as reflecting, to the maximum possible extent, the designer's intent at each level. This strategy should provide both a reduced design time, and protection against over-designed systems. The implementation of a design environment that supports this futuristic scenario will be challenging, since it will require standards for capturing design data as well as ones that enable a large team to collaborate on a design simultaneously, and perhaps remotely. If design constraints are introduced too early, or for reasons other than to address true functional requirements, a heterogeneous design environment (one incorporating a variety of design tools) may not be capable of efficiently generating a complete design, and the reuse of design blocks may only be possible within the tools that initially were used to create them. Dr. Chang continued with the description of an alternative design approach which he felt would provide better tool integration: the use of predesigned functional blocks containing both analog and digital circuits and having functions described less specifically than is the case for current library design blocks.

Different types of designs are needed to provide functionality, connectablity between blocks, and to tie system functionality to specifications and requirements. These requirements drive the need to provide design blocks which have multiple "views" that collectively incorporate all of these considerations in a usable manner, as well as providing more detailed information such as the semiconductor processing required, the physical design data related to the logical design, and an enumeration of the design tools that can utilize the data.

Dr. Chang cited the need for increased participation in such projects and described Cadence's strategy:

- Practical staged methodology
- Linchpin technologies for each stage
- Methodology/technology transition services
- Partners/services to help build portfolios

He commented that all of these are happening today.

DR. RONALD REEDY – PEREGRINE SEMICONDUCTOR
ULTRA-THIN-SILICON (UTSI) TECHNOLOGY AND ITS HIGH RELIABILITY APPLICATIONS

The key element of Dr. Reedy's presentation was that Thin Film Silicon on Sapphire (TFSOS) CMOS has the high-reliability requirements essentially built-in at the die level. Therefore, no special wafer processing or design is required to meet special high-reliability performance issues. Special back-ends such as packaging, test and qualification must be applied, but the critical elements of design and fabrication are provided by established manufacturing lines. As back-end support is much easier to find and maintain than design and fabrication, high-reliability products can be supplied (by Peregrine and others) with the same confidence as commercial products.

A second point, strongly emphasized, was that, since TFSOS (or UTSi, Peregrine trademark) products are CMOS based, the path to the future is the same as that of CMOS. His view was that exotic processes without commercial pull will always be endangered. With the costs of fabrication and the opportunity of value of design driving all companies to commercial markets, use of non-commercial design and fabrication will be at risk due to potential supply discontinuities.

Finally, for integrated RF products, he stated that the key issue is the substrate, not the transistors. He commented that while GaAs is an acceptable substrate, in his view, it cannot match the availability, integration complexity, flexibility (digital logic, p-channel device), low power and cost of TFSOS CMOS. Any other solution using a finite resistivity substrate will suffer from lack of isolation between its various circuit functions, specifically between the digital and analog portions.

MR. AARON CORDER – ARMY SPACE AND MISSILE DEFENSE
U.S. ARMY APPROACH TO ANALOG SILICON INTEGRATED CIRCUIT INVESTMENTS

Mr. Corder addressed the need for radiation hardened high performance electronics. He focused on the needs for satellite and missile systems, and how electronics that had not been specifically hardened are employed for hardened system applications. To that end, he displayed roadmaps showing the upgrade paths in CMOS and bipolar technologies for a variety of key systems. The approach centered around leveraging advancing commercial technology through introducing design and process modifications to achieve the required hardness.

In reviewing the attributes of technology candidates to meet these needs, Mr. Corder noted that XFCB (eXtra Fast Complimentary Bipolar) technology provides transistors resistant to total dose and latchup from heavy ions or ionizing dose. He cited a number of part types being produced and good radiation testing results on NPN and PNP transistors. He detailed the radiation tolerance of Analog Devices' ADCs, available in different qualification levels for commercial and military temperature environments. The strategy he outlined involved investment in commercial foundries, Analog Devices,

multi-level radiation foundries, Honeywell, Lockheed, and Harris; and, linear radiation multi-level design automation tools as well as testing.

DR. BERNARD XAVIER – HUGHES NETWORK SYSTEMS
BROADBAND METAL OXIDE SEMICONDUCTOR (MOS) RADIO RECEIVER CIRCUITS

Dr. Xavier emphasized several points, which are summarized as follows.

He noted that CMOS RF is currently an active area of research for many companies and universities. The motivation behind this investment is derived from the potential cost benefits the technology promises to bring to commercial products in the communication arena. He described that CMOS has several unique benefits which bipolar technology does not offer. The technology offers high performance sampled data systems such as switched capacitor filters. This in turn enables the development of high performance Delta Sigma ADCs and DACs that are not available in a bipolar technology.

Modern communication equipment employ complex modulation schemes that benefit from enhanced signal processing of the received and transmitted signals. Thus, receivers require ADCs and DACs in order to operate. Wider dynamic range ADCs and DACs allow the expensive and bulky filter specifications to be relaxed which results in a direct cost savings and size reduction in the receiver equipment. Eventually more and more of the RF/ Intermediate Frequency (IF) functionality of the receiver will migrate towards CMOS technology because of cost and size, which are the major market drivers for commercial products.

The reason that CMOS offers improved dynamic range over bipolar technology in circuits such as mixers and LNAs is because the square law equation that governs device operation is a weaker non-linearity than the exponential law that predicts bipolar device operation. This has already been cited in numerous papers. Silicon-on-Sapphire (SOS) has some benefits unique to this technology since the substrate is insulating. These benefits are derived mainly from the isolation of the process which leads to wider range automatic gain control (AGC) circuits, better stop band performance of on-chip filtering, lower switching noise feedthrough which would otherwise degrade the performance of Delta Sigma modulators, and higher Q spiral inductors because eddy currents flowing in the substrate are reduced.

To qualify CMOS as an RF process, several circuits along with measured results were discussed. A Gilbert Cell mixer and dual-gate mixer were presented and contrasted with a typical bipolar mixer. Very wideband circuits were discussed including a distributed amplifier and a distributed mixer that had bandwidths from 300 kHz through 4 GHz. These circuits can only be realized in Field Effect Transistor (FET) technology.

There are still some unresolved issues associated with the wide spread development of CMOS RF ICs, such as the effect of the Electrostatic Discharge (ESD) diode, process variations and 1/f noise contributions. However, companies specializing

in CMOS TFSOS RF such as Peregrine have some patents pertaining to CMOS ESD structures that largely overcome this issue. The use of wide range AGC, which TFSOS implementations offer, corrects for process variation. The 1/f noise leads to close in carrier noise around the LO signal in a Voltage Controlled Oscillator (VCO). This noise is up-converted by the non-linearities associated with the transistor. However, CMOS has a lower conversion gain than bipolar technologies, and thus, this may not be the issue it at first appears.

DR. LAWRENCE LARSON - UCSD
THE FUTURE OF SILICON-BASED ANALOG INTEGRATED CIRCUIT TECHNOLOGY

Dr. Larson described the changing system scenario in which there is an increasing amount of silicon with the III-V components focusing on the highest performance. He commented that for many RF applications, standard silicon technologies now have sufficient speed. He noted that SiGe HBT performance is comparable to GaAs Metal Semiconductor Field Effect Transistors (MESFETs) at 2.4 GHz.

However, there are a number of outstanding, unsolved problems in analog/RF ICs. These include:

- High Q, tunable, linear, microelectronic filters.
- Power amplifiers, with high efficiency over a full range of output powers.
- Data converters with higher resolution and speed.
- Low cost higher frequency (5-60 GHz) technology for wideband wireless data applications.

He concluded that analog/RF microelectronics is moving towards more highly integrated combinations of digital and analog signal processing that will have major impact. However, for the highest performance levels, he noted that new architectures are still required for fundamental breakthroughs.

COMMITTEE FINDINGS AND RECOMMENDATIONS

FINDINGS

- Military systems have higher percentages of analog components than commercial systems.
- The greatest concerns in the area of analog components focused on the performance and supply of ADCs.
- Analog components, in particular ADCs, do not enjoy the same rate of improvement as digital circuits as technology improves. There appear to be fundamental limitations that are not thoroughly understood.
- While there is a considerable, albeit not large, business in analog components, it is focused on commercial requirements for low cost, low speed ADCs.
- The demand for higher performance analog components for near term system insertion continues, but the sources for these devices are decreasing and the performance is insufficient.
- This demand for higher performance provides an incentive for the development of GaAs, InP, and SiGe technology for analog components.
- Most Government programs, including research and development efforts, target requirements for individual applications rather than the challenging technical issues limiting progress in ADCs. Emphasis has been on exploitation rather than understanding underlying technical barriers.
- Integration, i.e., a single chip, is not the most likely solution for increasing system performance and reducing costs.

RECOMMENDATIONS

1. Programs exploring the current limitations of ADCs and the underlying causes would be worthwhile investments for the DoD.
2. Projects should address the entire life cycle, analysis and design, as well as proof of principle through fabrication and test.

3. Consider that significant system cost reductions may be achieved through the use of key specialty (non-COTS) components that reduce overall parts counts or simplify architectures.

4. Invest where other investors support the infrastructure costs.

5. Be prepared to reduce or waive expectations for cost sharing, no fee, IP sharing, etc. for areas where markets for DoD requirements are small, to encourage participation and investment.

6. Programs investigating space requirements (i.e., radiation-hardened, low power) for analog ICs are a needed DoD investment as the military migrates its assets to space. The current trend of major IC suppliers abandoning the military IC business will make this an increasingly difficult task.

APPENDIX A

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW ON MIXED-SIGNAL COMPONENTS

AGENDA: SESSION 1

Military Needs for Mixed-Signal Components

17 September 1997

Analog-to-Digital Converters: Survey and Analysis
Dr. Robert Walden
Principal Research Scientist
Microelectronics Laboratory
Hughes Research Laboratories
9:00

Analog Integrated Circuit Requirements for Government Systems
Presented by
Dr. Robert Walden
For
Dr. Michael Delaney
Chief Scientist
Government Electronics
Hughes Space and Communications
9:30

Analog-to-Digital Converters for Future Military Systems
Mr. Brian Wong
Manager
Mixed Signal Products
TRW
10:00

Analog Electronic Signal Processing
Mr. Anthony Spezio
Supervisory Engineer
Electronic Warfare Systems
Naval Research Laboratory
10:30

Radar Requirements for Analog Integrated Circuits
Mr. Todd Kastle
Acting Technical Director
Radar Branch
Air Force Wright Laboratories
11:00

Radiation-Hardened Electronics Review
Mr. David Emily
Manager
Technology Development Branch
Naval Surface Warfare Center – Crane
11:30

LUNCH
12:00

Analog Integrated Circuits for Next Generation Test Equipment
Mr. Major Fecteau
Physicist
Army Test, Measurement and Diagnostic Equipment Activity
1:00

Aftermarket Support Capabilities for Analog Integrated Circuits
Mr. Keith Meyer
System Engineering Technologist
Tracor Engineering Systems
1:30

The Challenges & Solutions to Analog Design
Dr. Robert Ewing
Adjunct Professor
Department of Electrical Engineering
Air Force Institute of Technology
2:00

Radar Needs for Analog Devices
Mr. J. P. Letellier
Branch Head
Advanced Radar Systems
Naval Research Laboratory
2:30

Trends in Commercial Analog-to-Digital Converter Technology
Dr. Dennis Buss
Vice President of Technology
Analog Devices
3:00

Electronic Warfare Analog Integrated Circuit Requirements
Material submitted for review by
Mr. Raymond Irwin
Chief Engineer
Night Vision & Electronic Sensors Directorate
Army Communications and Electronics Command
3:30

APPENDIX A (cont.)

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW
ON
MIXED-SIGNAL COMPONENTS

AGENDA: SESSION 2
Investment Strategies for Mixed-Signal Components
11 December 1997

Radiation-Hardened Analog Technology Developments
Mr. Charles Tabbert
Manager of Technology for the Military and Space Line
Harris Semiconductor
9:00

Future of Silicon-Based Analog Integrated Circuit Components
Mr. Thomas "Stony" Edwards
Managing Director, Government Technology Unit
National Semiconductor
9:30

Texas Instrument's Future Plans for Mixed Signal Integrated Circuits
Mr. Brad Little
Strategic Marketing, Military Products
Texas Instruments
10:00

Mixed Signal Design in System-On-A-Chip Transition
Dr. Henry Chang
Consulting Staff Member
Cadence
10:30

BREAK
11:30

Ultra-Thin-Silicon Technology and Its High Reliability Applications
Dr. Ronald Reedy
President and Chief Executive Officer
Peregrine Semiconductor
11:45

U. S. Army Approach to Analog Silicon Integrated Circuit Investments
Mr. Aaron Corder
Linear Technical Manager
Army Space and Missile Defense Command
12:15

Broadband MOS Radio Receiver Circuits
Dr. Bernard Xavier
Director of VLSI
Hughes Network Systems
12:45

The Future of Silicon-Based Analog Integrated Circuit Technology
Dr. Lawrence Larson (via telephone)
Professor of Electrical and Computer Engineering
University of California at San Diego
1:15

APPENDIX B

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW ON MIXED-SIGNAL COMPONENTS

TERMS OF REFERENCE

Purpose

The purpose of this STAR is to provide the DoD with recommendations about how to meet future military needs for mixed-signal components. The STAR will convene two sessions of expert presentations. The first will focus on ascertaining the DoD's need for analog IC components for various applications. The second session will bring together a panel of experts to address the ability of current and anticipated designs in meeting the identified needs. This meeting also will compare the costs and benefits of silicon-based versus III-V-based material technologies in analog IC applications. The final report will include a characterization of the current silicon-based analog IC supply base and anticipated developments within this industry. For the purpose of the STAR, silicon-based material technologies will include: (1) bulk silicon, (2) silicon-germanium, (3) silicon on insulator, and (4) silicon on sapphire.

Supporting Objectives

- To survey future military needs, in terms of parameters and/or functions, for analog IC components (both classified and unclassified).
- To determine the *ability* of state-of-the-art silicon-based analog IC technologies to meet future military needs.
- To ascertain the *availability* of both COTS and custom analog IC components for meeting future military needs and to classify providers according to capabilities.
- To compare ongoing silicon-based analog IC research initiatives sponsored by DoD with future military needs so as to determine how best to focus support.
- To identify which DoD silicon-based analog IC research initiatives have the necessary commercial infrastructure to support product development.
- To evaluate the *adequacy* of commercial design protocols for meeting future DoD design needs and to assess the cost-effectiveness of opportunities for developing new design tools/simulators that may be required for higher performance silicon-based analog ICs.
- To gauge commercial sector *interest* in developing new design capabilities for mixed-signal components (possibly via a "NSA-type" approach wherein prototype chips are sent to suppliers to determine which have the capability to manufacture them).
- To establish the relationship between COTS components and final system products meeting military specifications and to assess the need for developing standard tools to

facilitate the transfer of product developments between design and manufacturing organizations.

- To judge the ability of DoD to *routinely identify* its emerging needs for mixed-signal components and to *regularly assess* industry design and manufacturing capabilities for meeting those needs. The final report will make appropriate recommendations in this regard where necessary.
- To *gather information* about anticipated commercial developments in silicon-based analog ICs for DoD to use in planning future systems using this class of devices.

Key Issues

- Evolving DoD needs. What aspect of the current state of analog IC devices creates the greatest hindrance to further development of the technology? What are the technology drivers? The following factors will be considered:
    - Performance. Example: ADCs (higher resolution, bandwidth, lower power).
    - Integration levels. Examples: MEMS, mixed signal, physical-to-analog converters, and microwave applications.
    - Process reproducibility/design simplicity. Example: OPAMP 740.
    - Cost/affordability.
- Anticipated development of the technology. Although the upward trend in world market revenues for analog ICs is expected to continue (+11% from 1993 to 1997), the market share of analog versus total ICs will remain fairly constant (25.9% in 1993; 26.2% in 1997).
    - What technology advances will be needed to ensure cost-effective fabrication of silicon-based analog ICs? How difficult will these advances be to implement? How far and how fast can DoD progress with present technologies (such as dielectric isolation)? What components, circuits, and systems will silicon-based analog ICs make possible? When? Are ongoing research projects addressing these needs? What are the limitations currently preventing the fulfillment of military applications (such as radiation-hardened requirements)? Is DoD cost limited? Technology limited? Market limited?
    - Identify and assess major potential problems including:
        - Model and design tool adequacy.
        - Voltage level and scaling issues. (The problems of shrinking dimensions and scaling paths for silicon-based analog ICs have not been worked out; there is no protocol for shorter dimensions or lower voltage levels.)
        - Transistor matching concerns. (This is a tougher problem at smaller dimensions for analog ICs).

- COTS suitability. Compared to a digital final product, it is more difficult for an analog final subsystem to meet the needs of the military (particularly radiation hardness and temperature range). Consequently, one may anticipate that there will be fewer COTS parts available to satisfy military analog circuit requirements. This raises a number of important issues:

    - Is there a risk for silicon-based analog ICs to be "out of the digital industrial mainstream"? What will be the resulting technical and business impact? How might the dissimilarities (analog vs. digital technologies) be lessened?

    - If one were to generate an "analog" roadmap, how many technology/process/design deviations (from the digital industrial infrastructure) should be implemented? What resources should be allocated? Over what time periods?

- Economic and manufacturing issues. The following will need to be fully analyzed:

    - Si (bulk) vs. SiGe vs. SOI vs. SOS
    - Will industry be able to satisfy military requirements? Where should the bulk of silicon-based analog IC (DoD and industry) funding be applied? Over what time periods? At what levels? At what priority?

APPENDIX C

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW ON MIXED-SIGNAL COMPONENTS

ACRONYMS, ABBREVIATIONS AND DEFINITIONS

A/D, A/DC, ADC .... Analog-To-Digital Converter
AFIT .... Air Force Institute of Technology
A/G .... Air to Ground
AGC .... Automatic Gain Control
AGED .... Advisory Group on Electron Devices
ASIC .... Application Specific Integrated Circuit
BIFET .... Bipolar Field Effect Transistor
BMDO .... Ballistic Missile Defense Organization
BW .... Bandwidth
CAD .... Computer Aided Design
CD .... Compact Disk
CMOS .... Complementary Metal Oxide Semiconductor
COMM .... Communications
CONOPS .... Concept of Operations
COTS .... Commercial-Off-The-Shelf
CPU .... Central Processing Unit
CW .... Continuous Wave
D/A, D/AC, DAC .... Digital-To-Analog Converter
DARPA .... Defense Advanced Research Projects Agency
DDS .... Direct Digital Synthesis
DMS .... Diminishing Manufacturing Sources
DoD .... Department of Defense
DoE .... Department of Energy
DSP .... Digital Signal Processor
DSWA .... Defense Special Weapons Agency
EDA .... Electronic Design Analysis
EM .... Electromagnetic
ENOB .... Effective Number of Bits
ESD .... Electrostatic Discharge

ESM ....Electronic Signal Measurement
EW ....Electronic Warfare
FET ....Field Effect Transistor
FM..Frequency Modulation
FMBW ....Frequency Modulation BandWidth
FOV..Field-Of-View
FSR ....Future Surveillance Radar
GaAs ....Gallium Arsenide
GPS ....Global Positioning Satellite
GP-TMDE..General Purpose Test, Measurement and Diagnostic Equipment
GSPS ....Giga Samples Per Second
HBT..Heterojunction Bipolar Transistor
HF ....High Frequency
HPRF ....High Pulse Repetition Frequency
HRM ....High Resolution Mode
IC..Integrated Circuit
ID ....Identification
IF ....Intermediate Frequency
InP ....Indium Phosphide
IO ....Input-Output
IR..Infrared
LEO..Low Earth Orbit
LNA ....Low Noise Amplifier
LO ....Local Oscillator
LTCC ....Low Temperature Cofired Ceramic
MEMS..MicroElectroMechanical Systems
MESFET ....Metal Semiconductor Field Effect Transistor
MIC ....Microwave Integrated Circuit
MMIC ....Monolithic Microwave Integrated Circuit
MOS..Metal Oxide Semiconductor
MPM ....Microwave Power Modules
MPRF..Medium Pulse Repetition Frequency
MSPS ....Mega Samples Per Second
NASA..National Aeronautical and Space Administration
NRL..Naval Research Laboratory
NSA..National Security Agency
NSC..National Semiconductor Corporation

NSWC ....Naval Surface Warfare Center
OEM..Original Equipment Manufacturer
OPAMP ....Operation Amplifier
OUSD (A&T)/DDR&E/SE&BE ....Office of the Undersecretary of Defense for Acquisition and Technology/Director of Defense Research and Engineering/Sensors, Electronics and Battlefield Environment
PEM ....Plastic Encapsulated Microcircuit
PLL ....Phase Locked Loop
QFT ....Quantitative Feedback Theory
R&D...Research and Development
RF...Radio Frequency
RGHPRF ....Range Gate High Pulse Repetition Frequency
SATCOM...Satellite Communications
SEI...Specific Emitter Identification
SEM ....Standard Electronic Module
SFDR ....Spurious Free Dynamic Range
Si ....Silicon
SiGe...Silicon Germanium
SNR...Signal to Noise Ratio
SOI ....Silicon on Insulator
SOS ....Silicon on Sapphire
SPAWAR...Space and Naval Warfare Systems Command
STAR ....Special Technology Area Review
TE..Thermoelectric
TFSOS ....Thin Film Silicon on Sapphire
T/R ....Transmit/Receive
TWT ....Traveling Wave Tube
UHF...Ultra High Frequency
UTSi..Ultra Thin Silicon
VCO ....Voltage Controlled Oscillator
VHDL ....VHSIC Hardware Description Language
VHDL-AMS ....VHDL-Analog Mixed Signal
VHSIC...Very High Speed Integrated Circuit
VHF...Very High Frequency
VLSI..Very Large Scale Integration
XFCB ....eXtra Fast Complimentary Bipolar

APPENDIX B

HIGHEST S&T ELECTRON DEVICE PRIORITIES OF THE DEPARTMENT OF DEFENSE

1. DEVELOPMENT OF HIGH PERFORMANCE MICROWAVE AND MILLIMETER WAVE INTEGRATED CIRCUITS, VACUUM ELECTRONICS, AND RELATED PACKAGING AND INTERCONNECTION TECHNOLOGY

   - High power, high efficiency MMICs: especially millimeter-wave power amplifiers and low noise receiving amplifiers
   - Associated passive componentry such as thin-film miniature circulators, filters, mixers, etc.
   - High power vacuum electronics
   - Very advanced components for phased arrays (high risk, high payoff)
   - Highly integrated packaging and interconnection techniques including multi-chip modules and 3-dimensional approaches; these would be used, for example, to develop very compact, shallow depth phased arrays for platforms such as small satellites or UAVs and for digital receivers
   - Completion of integrated suite of CAD tools for microwave systems and sub-systems with standardized interconnections to allow compatability between tools from multiple vendors; development of common language for improved facilitation of use of design tools and to greatly reduce NRE costs
   - Independent assessment of device and circuit reliability
   - Development of advanced, highly efficient manufacturing and assembly techniques to drive down module/subsystem assembly costs
   - Frequency control components for highly accurate, highly stable clocks and oscillators

2. ANALOG-TO-DIGITAL CONVERTERS

   - With high number of effective bits, wide bandwidth, large spur-free dynamic range, very low power dissipation and high radiation resistance (> 500 MHz input frequency, up to 16 effective bits with multi-GHz bandwidth and > 80 dB spur-free dynamic range needed for radar and EW applications)

   - Exploration of photonic-based as well as electronics-based architectures

3. EXPLORATION OF PHOTONIC SOLUTIONS FOR HIGH PERFORMANCE, MULTI-SENSOR ACTIVE ARRAYS , HIGHER PERFORMANCE COMPUTING AND MEMORIES

   - Development of photonics related components including higher performance vertical cavity surface effect lasers (VCSELS) and sensitive photodetectors
   - Exploration of increasingly dense and complex interconnection structures
   - Development of manufacturing capabilities resulting in low cost, reliable assembly

4. SURVIVABILITY OF MICROELECTRONIC DEVICES AND CIRCUITS INCLUDING RADIATION HARDNESS

5. HIGH RESOLUTION, LOW POWER MINIATURE DISPLAYS (including integration of processing and storage elements and continuation of research on new technologies such as visual retinal displays)

6. INFRARED FOCAL PLANE ARRAYS

- Aggressive development of large pixel count (up to 2048 x 2048) high sensitivity arrays, both cooled and uncooled
- Smart FPAs with integrated supporting electronics
- Multispectral arrays including development of improved UV/IR detectors

7. DEVELOPMENT OF HIGH POWER INFRARED LASER DIODE ARRAYS

- Particularly for use in IR Countermeasures applications requiring thousands of watts of power output

8. INTEGRATION OF HETEROGENEOUS, MULTI-FUNCTION, INTEGRATED CIRCUIT TECHNOLOGIES

- Development of interconnection and packaging approaches that allow reliable, efficient integration of microwave/millimeter wave, optoelectronic, IR, analog, digital , MEMS and MOEMS devices and circuits to produce compact, lightweight, low-power, very high performance, high reliability integrated electronics equipment suites
- Development of CAD tools, languages and equipment to allow efficient, appropriate selection and integration of best choices of electronic (photonic) components for particular missions

9. MICRO-ELECTRO-MECHANICAL SYSTEMS (MEMS)

- Development of methods and capabilities for production of reliable, low cost advanced micro-electrical-mechanical systems (MEMS) including combinations of MEMS with RF, optoelectronic, digital and analog devices
- Development of accurate CAD models and techniques for integration of MEMS CAD with RF, analog and digital CAD

10. MATERIALS FOR HIGH TEMPERATURE AND ADVERSE ENVIRONMENT OPERATION

- Highly focused efforts on production of silicon carbide substrates for active devices with minimum diameter of 3" and minimal defect densities (micropipes and screw defects); development of viable substrate material supply – important for producing needed high power microwave/millimeter wave devices and circuits and reproducible, reliable electro-optical devices
- Selective investments in development of advanced epitaxial structures, principally gallium-nitride based, to meet DoD needs for sources, detectors, and switching devices that can operate in adverse environments
- 6.1Angstrom lattice materials for mid-IR laser arrays (and InP)

11. HIGH ENERGY DENSITY POWER SOURCES INCLUDING FUEL CELLS FOR MILITARY FIELD APPLICATIIONS (for use in unattended locations and by individual personnel (e.g., soldiers))

12. BIOSENSORS FOR DETECTION OF TOXIC SUBSTANCES (including detectors for biological warfare)

13. DEVELOPMENT OF COMPONENTS REQUIRING ULTRA LOW POWER FOR OPERATION

- Advances by circuit redesign, shrinking dimensions, voltage reductions

Appendix C

A Description of AGED, Its Ojectives and Current Tasks

ADVISORY GROUP ON ELECTRON DEVICES (AGED)

What is AGED?

- A 55 year old DoD advisory body constituted under the Federal Advisory Committee Act--reports to the Director, Defense Research and Engineering
- A main group and three sub-groups (microwaves, microelectronics and electro-optics) of technical experts from government, industry and academia
- A forum for all of the Armed Services, DARPA, DTRA, BMDO, NASA and other Government agencies to discuss electronics issues, programs and program planning of importance to the DoD
- A source of current expert information and guidance about electron device and electro-optics technologies for use throughout the DoD

AGED's Objectives

To develop the best investment strategy for the DoD electron device program and describe serious electronics issues requiring ODDR&E attention

- To assist Reliance panels in efficiently meeting the electronics needs of all Services by:
  - identifying electronics investment areas of critical importance to all Services
  - assisting in the TARA process
- To serve as an honest broker, facilitating coordination and synergism among DoD components and other agencies

AGED Consultant Members Are Leaders In Industry and Academia

They include:

•Tom Hartwick	Chair, Former Chief Scientist, TRW
•Jack Kilby	Chair Emeritus, Inventor of the Integrated Circuit, IEEE Life Fellow, Recipient IEEE Medal of Honor
•Bill Howard	Former Senior VP and Director of R&D at Motorola, Member of Defense Science Board and National Academy of Engineering, IEEE Fellow, AAAS Fellow
•Charles (Chuck) Krumm	Chair, WG-A, General Manager, Raytheon's MMIC Facility, IEEE Fellow
•Conilee Kirkpatrick	Chair, WG-B, Vice President HRL Laboratories IEEE Fellow
•Andrew (Andy) Yang	Chair WG-C, Co-inventor S.B. IR Detectors & Cameras
•Barry Dunbridge	Asst. General Manager, TRW
•George Heilmeyer	Former President & CEO, Bellcore (now Telcordia Technologies), IEEE Fellow, Recipient IEEE Medal of Honor
•Paul Kelley	Professor, Tufts University

ALL SERVE AS "SPECIAL GOVERNMENT EMPLOYEES" SUBJECT TO STRINGENT RULES & REGULATIONS WHILE CONDUCTING AGED BUSINESS

Advisory Group Key Tasks

- Assist TPED in developing a comprehensive DoD electronics S&T strategy utilizing TPED roadmaps as an integrated planning vehicle
- Identify and review trends in technical progress and funding of electron device programs as they relate to the S&T strategy
- Conduct in-depth Special Technology Area Reviews (STARs) of promising new approaches, suddenly emerging problems and other technical developments of a high-leverage nature
- Provide assistance and enhance the TARA process

AGED Reviews, Discusses and Provides Guidance on Issues of Importance to the DoD

In the past few years AGED has held Special Technology Area Reviews (STARS) on:

- The use of COTS electronics in DoD systems
- The future of Analog ICs
- Wide bandgap semiconductor materials, their usefulness for electronic devices and ultimately their use in DoD weapon systems
- The future of gallium arsenide MMICs
- MOEMS (Micro-opto-electrical-mechanical systems)
- (DoD) System Simulation
- Optical interconnect technology
- Frequency control devices
- Silicon-germanium technology
- Organic/Inorganic Nonlinear Electronic Materials
- Alternate Detector Materials to InSb and HgCdTe

AGED Government Members Are From Every Service, Many DoD Agencies and Other Government Agencies as well as FFRDCs

- AGED's DoD members and participants include senior managers and scientists from the Army, Navy, Air Force, DARPA, DTRA and BMDO
- In addition, representatives from NASA and NIST regularly attend meetings
- Representatives from Lincoln Laboratory, Sandia and Lawrence Livermore also are active associate members

What technology areas are currently discussed at AGED meetings?

- Microwave/Millimeter-wave monolithic ICs (MMICs) and modules
- Vacuum electronic devices
- Digital beamforming
- Photonics
- MEMS
- Wide bandgap semiconductor materials and devices
- Batteries and fuel cells
- Focal plane arrays
- Lasers
- A/D converters
- Computer Aided Design
- Advanced testing issues
- Radiation-hard devices and circuits

How does AGED Interact With Other DoD Electronics Groups?

AT PRESENT:

- AGED Main Group Member, Dr. William Howard, is member of Defense Science Board
- Many Service-appointed AGED members also serve as Reliance chairpersons or panel members
- AGED maintains close links with system developers throughout DoD and industry
- AGED has members and links to academia
- Many AGED consultant members are heavily involved in electronics developments for commercial applications

How AGED Has Made A Difference During the Last Five Years

- The AGED has assisted DoD Service members in preparing for Electronics TARA reviews so that presentations are succinct and effectively address issues of major importance.
- After TARA reviews, the AGED has assisted in resolution of open issues.
- The AGED has worked to foster interaction and cooperation between the Services and other agencies in S&T activities.
- The AGED tracks technical and financial trends of DoD. electronics programs serving as an effective corporate memory to help the DoD develop new electronics initiatives consistent with the strategic plan.

APPENDIX D

BENCHMARKING THE PERFORMANCE OF DoD LABORATORIES-- RELEVANCE and QUALITY

Introduction:

"Relevance" and "quality" are unquestionably appropriate measures of how well some DoD laboratories are performing their mission. For 6.1 basic research activities, relevance and quality are separable measures; i.e., they describe, to first order, the merit of this type of work within the DoD research laboratories. However, 6.1 basic research is a small fraction of the totality of laboratory work. Evaluation of a particular DoD laboratory is dependent upon the type of activities that it has as its mission.

Definitions of Relevance and Quality:

For 6.1 or basic research activities, relevance may be defined as how well the work being performed is leading toward increased fundamental knowledge and understanding in such areas as physical, engineering, environmental, and life sciences that are related to long-term national security needs. Quality may be defined by the traditional benchmarks of how many scholarly papers are accepted for publication in refereed technical journals or for presentation at prestigious technical conferences, the perception by peers of the importance and significance of the work being performed and the professional stature of the researchers.

Many DoD laboratories, however, do not perform basic research. Instead, they have missions requiring applied research (6.2), advanced technology development (6.3), demonstration and validation (6.4), engineering and manufacturing development (6.5) or RDT&E management support (6.6). For labs working on projects supported by funds from these budget categories, appropriate measures of relevance and quality are different. For 6.2 funded activities, relevance could be defined as how well the results of basic research are being used to design, develop and improve models or prototypes and formulate new processes. Quality could appropriately be defined as the success rate toward creating those prototypes of hardware or software or new methodologies. For 6.3 work, relevance might be defined as the ability to develop products and processes that meet the needs of DoD warfighters and cannot be produced by other organizations (i.e., industrial or commercial sources). Quality could be determined by assessing the robustness of those processes and the performance, reliability and affordability of the products developed. In many cases, very relevant and high quality 6.2 and 6.3 research and development activities also properly include work on adaptations of commercial/industrial/university processes or products to meet military requirements. Often the personnel engaged in these activities cannot publish as many scholarly papers as those engaged in 6.1 research because of the nature of the work they perform and sometimes because of restrictions due to security classification considerations.

For RDT&E activities in the 6.4-6.6 funding categories, relevance and quality measures are less representative than the ability to meet warfighters' needs with products (hardware and software) that reliably perform as required, under all anticipated environmental conditions and that can be obtained at an affordable cost.

Postscript:

I hope that the above addresses the questions posed at our meeting on Wednesday, November 17th. I would be pleased to provide any additional assistance you may deem useful.

Dr. Thomas S. Hartwick
Chairman, Advisory Group on Electron Devices

APPENDIX E

SAMPLE SUMMARY OF TECHNICAL ARTICLES

The following is a summary of the journal articles to be discussed at the September 27, 2000 meeting:

General Interest:

Techno-Warfare--Innovation and Military R&D **G-1**
An article by Senator Joseph Lieberman, published in the Summer 1999 issue of JFQ (Joint Forces Quarterly). Senator Lieberman points out that declining military budgets, resulting in reduced R&D, are causing severe limitations of the U.S. ability to maintain its dominant position in warfare technology. (*JFQ*, Summer 1999, p. 13)

The Future Is Networked **G-7**
A recent article by Senator Lieberman describing the importance of network-centric warfare. (*Defense News,* August 21, 2000, p. 15)

Vision 2020: U.S. Military Cannot Rely on Technological Advantage **G-9**
The Joint Chiefs of Staff believe that by 2020 the U.S. will not be able to sustain a significant advantage over adversaries through the use of superior technology in its weapon systems. They stated that "...flexible thinking and superior people skills will have to replace the high technological edge that U.S. forces have enjoyed for the past half century." (*Defense News,* June 26, 2000, p. 48)

High-Tech 'Silver Bullets' Could Revitalize Aerospace **G-11**
John A. Warden, 3rd, chairman and CEO of Prometheus Strategies Inc. and a former Air Force colonel, is gaining support for a proposal that DoD field at least one new weapon system per year, following a 1-3 year development cycle. The concept is called the New American Security Force (NASF). Only small numbers of each weapon would be placed in service but they would be expected to provide commanders with a wide range of strategic and tactical options. If a future U.S. President and key members of Congress are convinced of the NASF's value, the program could be implemented, according to its supporters, in less than 2 years. Implementing this program would almost certainly result in cancellation of the F-22 and Joint Strike Fighter programs. (*Aviation Week & Space Technology,* May 29, 2000, p. 58)

Defense Spending Choices Force A Balancing Act **G-13**
The U.S. is not willing to spend as much as it did previously to maintain military superiority. Thus, military systems must attempt to meet high performance and reliability requirements on much smaller budgets than were available in the past. (*Microwaves & RF,* June 2000, p. 29)

Industry Prognosis Flags Ominous Trends **G-19**
Results of a study by Booz-Allen & Hamilton on the state of the defense industry. Not surprisingly, the study concludes that the industry is continuing to grow weaker and that steps must be taken quickly to allow it to recover to an acceptable level. (*Aviation Week & Space Technology,* July 17, 2000, p. 28)

Government challenged to make high-tech careers more attractive **G-23**

Another article describing the problems facing the Government in recruiting and retaining sufficient numbers of highly qualified high-tech engineers. This article is based upon a report entitled "Ensuring a Strong US Scientific, Technical and Engineering Workforce in the 21st Century", which was written by the National Science and Technology Council. Members of this council include the President, Vice President, and heads of federal agencies with primary responsibility with science and technology. (*Laser Focus World,* June 2000, p. 58)

Poor Management Plagues EW Programs **G-25**

Peter Lennon, former Senate staffer and presently DoD director for acquisition resources and analysis, headed a study team that concluded that rapid obsolescence, delays in new programs and cost overruns are plaguing the U.S. military's electronic warfare (EW) systems efforts. The study calls for new oversight of EW programs across the Department of Defense. (*Defense News,* August 7, 2000, p. 1)

Where have all the [technical] people gone? **G-27**

An editorial by the Editor in Chief of *Laser Focus World*, focusing attention on the shortage of laser and electro-optics engineers and scientists. (*Laser Focus World,* June 2000, p. 5)

Declining Investment In Research and Development Alerts Defense Industry **G-29**

Aerospace Industries Association (AIA) registers its concern about the continuing decrease in the DoD R&D budget. According to the AIA, when inflation is taken into consideration, the FY 2001 RDT&E budget is at the lowest level it has been in 18 years. AIA wants a $2 billion increase in DoD funding of aerospace RDT&E in FY 2001. (*Microwaves & RF,* June 2000, p. 26)

Pentagon Arms Revamp Plan Draws Praise **G-31**

Positive comments have been received from industry about the DoD plans to change its weapon acquisition strategy. The key change that will be implemented in the revised process is to reduce from the number of milestones, from four to three, used to assess progress of major weapon development from laboratory demonstration to fielding. (*Defense News,* June 19, 2000, p. 4)

DoD Panel Wants To Lift Industry's Bottom Line **G-33**

A Defense Science Board (DSB) panel is recommending that the defense industry be able to increase its return on investment for DoD contracts. If the recommendations are enacted, higher profit margins will be allowed and independent research and development (IR&D) will be enhanced by allowing defense contractors to collect a profit from it. (*Defense News,* July 3, 2000, p. 20)

FCS Development Key to U.S. Army Transformation **G-35**

The success of the Army's Future Combat System (FCS) program is critical for assuring that the Army can meet its objective of quickly remaking itself into a lighter, learner combat force that will principally used wheeled vehicles. $1.8 billion has been budgeted over the next 5 years to develop and demonstrate FCS. The Army and DARPA have awarded 4 $10 million contracts for the development of FCS design concepts to: Boeing Co (Seattle, WA), Science Applications International Corporation (McLean, VA), TEAM FoCuS Vision CONSORTIUM led by Raytheon (Plano, TX) and Team Gladiator which includes TRW (Carson, CA) and Lockheed Martin (Bethesda, MD). (*Defense News,* July 10, 2000, p. 8)

Lighter Vehicles on Wheels Perform Similarly To Tracks in U.S. Army Study for Interim Brigade **G-37**

The Army has found no significant difference between the performance of wheeled and tracked vehicles for use in its medium-weight interim brigades. The evaluations were performed at Aberdeen Proving Grounds in Maryland. Testing and analysis will continue, focused on whether or not there is an anticipated advantage of one type of vehicle over another for life cycle costs. The winner of the competition will be announced by September 4. (*Defense News,* July 31, 2000, p. 18)

Electronic Systems Enhance Apache Survivability **G-39**

Apache helicopters will be outfitted with new electronic warfare systems including the Suite of Integrated Radio Frequency Countermeasures (SIRFC) and the Suite of Integrated Infrared Countermeasures (SIIRCM). These will improve situational awareness by allowing flight crews to detect and track missile launches and process combat data faster. (*Defense News,* July 31, 2000, p. 3)

Gerald M. Borsuk; Frederik Philips Award **G-41**

Dr. Gerry Borsuk, Superintendent of NRL's Electronics Science and Technology Division and Navy Deputy AGED Member, has been awarded the Frederik Philips Award "for managerial and technical leadership in directing the creation and transition of new materials and devices into electronic systems." Congratulations to Gerry! (*IEEE Spectrum,* August 2000, p. 66)

Clark Plan Boosts Status of U.S. Navy Fleet Readiness **GRECENT-1**

Additional information about Admiral Vernon Clark's plans to restructure the Navy's management hierarchy. The plan calls for a new office called the Office of the Deputy Chief of Naval Operations for Fleet Readiness and Logistics. This office will have responsibility for setting requirements and policy for aviation, ship and submarine readiness; advocating ordnance readiness and setting policy for munitions storage, movement and inventory management but, more importantly, deciding how many and what types of munitions the fleet needs to buy; and for establishing requirements for sealift and combat logistics force ships. Creating this new office with its emphasis on fleet readiness is expected to result in the transfer of control of billions of dollars from existing offices for aviation, ships and submarines. (*Defense News,* September 18, 2000, p.1)

U.S. Navy Chief May Shift Billions of Budget Dollars **G-43**

Admiral Vernon Clark, the new Chief of Naval Operations, stated at his Senate nomination hearing that he expects to redirect a major portion of the U.S. Navy's budget toward assuring that the fleet is funded and current forces are upgraded. Modernization is ranked a distant third in Admiral Clark's priorities. (*Defense News,* June 4, 2000, p. 1)

Clark Resurrects U.S. Navy Warfare Directorate **G-45**

Admiral Clark will establish a new directorate called the Directorate for Naval Warfare that will serve as an overarching directorate for various specific warfare directorates. This is the first time since 1992 that such a directorate has existed. The new organization, called N9, will be responsible for developing future fleet requirements and determining the best mix of ships, aircraft and subs for future Naval combat. The existing warfare directorates, known as N8, will have their role altered to focus on resources and budget issues. (*Defense News,* August 14, 2000, p. 18)

U.S. Navy Budget Takes A Hard Hit **G-47**

The Navy's six-year Program Objective Memorandum (POM) predicts that the necessity for maintaining zero real growth in defense spending over the next several years will result in the Navy not being able to fund a number of its high priority efforts. These include ballistic missile defense, network centric warfare initiatives, buying ships and aircraft at higher levels to reduce acquisition costs, replacing the EA-6B EW aircraft and producing the Multimission Maritime Aircraft. (*Defense News,* July 3, 2000, p.1)

U. S. Navy To Study Radar Needs Yet Again **G-49**

The U.S. Navy will once again reassess its radar needs. In addition, Dr. Jacques Gansler, is calling for the establishment of a Radar Industrial Capability Integrated Product team to study the overall condition of the radar industrial base in the United States and assess the impact of acquisition decisions currently under consideration. (*Defense News,* June 12, 2000, p. 1)

Pentagon To Analyze U.S. Radar Capabilities **G-51**

As noted above, Dr. Gansler has ordered a new study to evaluate the capabilities of the U.S. radar industrial base. The question is whether or not new policies are needed to protect or aid this portion of the defense industrial base. (*Defense News,* July 31, 2000, p. 2)

Legal Dispute Snarls Progress on CEC Upgrade **G-53**

Lockheed Martin and the Navy are disagreeing about incorporating a novel technology to add theater missile defense capabilities to version 2.2 of the Cooperative Engagement Capability (CEC) system. The new technology is called Tactical Component Network; it has been developed by Solipsys of Laurel, MD. Its claimed advantage is the ability to move large amounts of data quickly around the CEC network. It also is said to allow more users to be part of the CEC network while, at the same time, conserving bandwidth. The Navy's contract and legal department has ruled that incorporating this technology into CEC 2.2 is outside the scope of the (existing) contract. (*Defense News,* June 5, 2000, p. 3)

Industry Team Picked For Navy UCAV **G-55**

The Navy has awarded contracts to Boeing and Northrop Grumman for Unmanned Combat Air Vehicles (UCAVs). The vehicles are expected to be used for surveillance purposes. A particular objective for the contractors is to develop effective launch and recovery methods. (*Aviation Week & Space Technology,* July 10, 2000, p. 35)

U.S. Air Force's F-22 Raptor Program Safe **G-57**

The Air Force will receive an overall FY 2001 budget of $84.1 billion with $7.6 billion designated to purchase new aircraft, including the F-22 Raptor. The F-22 program will receive full funding as long as the aircraft meets its Congressionally required testing deadlines. (*Defense News,* July 31, 2000, p. 6)

Spy Tech **G-59**

A description of the CIA's new venture capital firm In-Q-Tel. In-Q-Tel has received $28 million from Congress to invest in technologies of interest to the CIA. Its board of trustees includes Norm Augustine, Paul Kaminski and Bill Perry. It is currently working with eight companies, primarily on information technology programs. (*Washington Business Forward,* June 2000, p. 53)

DoD plans first exercise in August to use Internet for sensor fusion **G-65**

DoD will conduct joint-Service exercises in August to test the ability of sensor-fusion technologies developed under the Smart Sensor Web program to improve situational awareness on the battlefield. (*Military & Aerospace Electronics,* June 2000, p. 1)

Raytheon To Build Radars for THAAD **G-67**

Raytheon will receive more than $1.4 billion to design, develop and manufacture three X-band phased array radars for the Army's Theater High Altitude Area Defense (THAAD System. The contract was received from Lockheed Martin Corporation, the THAAD program's prime contractor. (*Defense News,* September 4, 2000, p.21)

Raytheon and Thomson-CSF Plan Joint Venture in Radar **G-69**

Thomson-CSF and Raytheon have entered into a joint venture to develop ground-based radar and air defense command and control systems. Systems that will be addressed include Raytheon's AN/TPQ-47 Firefinder battlefield weapon locator system. (*Defense News,* July 3, 2000, p.1)

JSF Studied As Potential Jamming, Laser Platform **G-71**

Lockheed Martin is looking at offshoots of its Joint Strike Fighter candidate aircraft that can be used primarily for electronic attack and delivery of directed-energy weapons. (*Aviation Week & Space Technology,* July 10, 2000, p. 33)

Congress Trims JSF Funding **G-73**

Congress has reduced the JSF budget for next year to $688.6 million. This is approximately $170 million less than approved in the defense authorization bill. Of this amount only $101.3 million is for engineering manufacturing development (EMD), a large reduction from the President's budget of $299.5 million. (*Aviation Week & Space Technology,* July 24, 2000, p. 62)

New Weapons, Tactics Explored for JSF **G-75**

Several companies are developing advanced capabilities for the JSF. Boeing's design allows a pilot to open one bay door for either radar or weapon deployment purposes while keeping the other closed to preserve stealth capabilities. Raytheon, is developing an anti-radar missile for the JSF which is smaller and has more capabilities than the High Speed Anti-Radiation Missile (HARM). Lockheed-Martin is also working on advances for the JSF. (*Aviation Week & Space Technology,* August 7, 2000, p. 44)

New Radar Would Meld AWACS, J-STARS Roles **G-77**

The Air Force is planning development of a new aircraft that combines the capabilities of the E-3 AWACS air-to-air surveillance aircraft with those of the E-8 Joint-STARS. Two current radar development programs are in serious jeopardy: the Radar Technology Insertion Program (RTIP) and the Discoverer II satellite constellation. (*Aviation Week & Space Technology,* June 12, 2000, p. 29)

Pentagon Demands Radar Upgrade Accord **G-79**

Raytheon and Northrop Grumman have been directed, by the Pentagon, to work jointly toward improving the radar system for the E-8 Joint-STARS long range, ground-surveillance radar aircraft. It will withhold funds for the upgrade program until the two companies agree on an acceptable joint strategy. (*Aviation Week & Space Technology,* August 7, 2000, p. 41)

Mald Makes Bid For New Missions **G-81**

Northrop Grumman hopes that its Miniature Air-Launched Decoy (Mald) will become an Air Force decoy-of-choice. It recently made an offer to the Air Force to build 150 of the Malds so that the Air Force would have a limited operational system available for emergency use. Mald was originally funded by DARPA and, currently, DARPA is supporting the development of a Mald derivative; a supersonic Miniature Air-Launched Interceptor (Mali) that could be used to defeat cruise missiles. (*Aviation Week & Space Technology*, July 10, 2000, p. 33)

Discoverer 2's Demise Will Not Stop Research **G-83**

Congress has terminated the Discoverer 2 radar satellite experiment. However, it provided $30 million to DARPA and NRO to continue work on space-based radar surveillance technology. A dedicated flight demonstration is specifically prohibited. (*Defense News*, July 31, 2000, p. 34)

USAF Makes Predator Its First Armed UAV **G-85**

The U.S. Air Force will test the ability of the Predator UAV to accurately bomb targets using a version of a small smart bomb. The bomb is a 250-pound class; GPS guided munition developed by the Air Force. Testing at Eglin AFB will be limited to those of inert weapons. (*Aviation Week & Space Technology*, June 12, 2000, p. 34)

U.S. missile defense system set for first full test in July **G-87**

DoD will test a prototype missile defense system at Kwajalein Missile Range on July 7th. This is the first test of a full-up system which includes a space-based early warning sensor, ground-based early warning, tracking and discrimination radars, battle management and command, control and communications, in-flight communications and the interceptor and kill vehicle. (*EE Times*, June 26, 2000, p. 34)

Support Falters for SBIRS Low **GRECENT-3**

Secretary of the Air Force, Whitten Peters, has stated that the Space Based Infrared System (SBIRS) Low satellite constellation program may be canceled. One reason for the diminishing interest in SBIRS Low is the recent deferral of a decision concerning whether or not to deploy a National Missile Defense system. . (*Defense News*, September 18, 2000, p.1)

U.S. Finds New Spy Satellites Too Expensive **GRECENT-5**

More bad news for military satellite systems. Plans have been dropped to develop new electronic spy satellites. Existing satellites will have their capabilities incrementally improved. . (*Defense News*, September 18, 2000, p.5)

Advanced Sensors Expand JSF Role; New Radar Design Uses Unique Building Blocks; Cool, Small, Cheap Defines Flexible Next Generation Radar; New Sensors Grab Extra Combat Roles; Sensors Cut From F-22 Appear on Joint Strike Fighter; Long-Range IR Sensor Extends JSF Shield (6 articles) **GRECENT-7**

A special section from *Aviation Week and Space Technology* describing the sensors to be used on the Joint Strike Fighter. The articles include two on the JSF radar system and another on its IR sensors, originally planned for use on the F-22.. (*Aviation Week & Space Technology*, September 11, 2000, p. 58-65, 74-76)

Sanders and other Lockheed Martin units to join BAE Systems **GRECENT-33**
Additional information about the acquisition of various Lockheed Martin companies by BAE Systems. (*Military& Aerospace Electronics,* September 2000, p. 3)

Readiness for Tomorrow **GRECENT-35**
Commentary by Frank Gaffney, President of the Center for Security Policy in Washington, about the consequences of the declining budget for development of future weapon systems. The article contains an interesting quote from Dr. Jacques Gansler, Undersecretary of Defense for Acquisition, Technology and Logistics. It is as follows: "We are trapped in a death spiral. The requirement to maintain our aging equipment is costing us more each year; in repair costs, down time and maintenance tempo. But we must keep this equipment in repair to maintain readiness. It drains our resources, resources we should be applying to modernization of the traditional systems and development and deployment of new systems." (*Defense News,* September 25, 2000, p. 23)

Chip sets accelerate 5-GHz wireless shift **GRECENT-37**
All CMOS, 5 GHz wireless-LAN chip sets are being produced by two fabless semiconductor startups in California. This opens a new frequency band for wireless service above the 2.4 GHz one. (*EE Times,* September 18, 2000, p. 1)

Plastic transistors raise hopes for flexible displays **GRECENT-39**
A 64 x 64 pixel liquid crystal display has been built at Philips Research Laboratories in the Netherlands with each pixel in the display controlled by a plastic transistor. This appears to increase the probability of low cost displays produced from polymers becoming available in the near future. (*EE Times,* September 18, 2000, p. 71)

Low-Price, Highly Ambitious Digital Chip **GRECENT-41**
A description of a CMOS chip being used by Eastman Kodak to produce 4096 x 4096 pixels per square inch, about twice the resolution of 35 mm film. Use of CMOS is expected to be lower cost than use of Charge Coupled Devices (CCDs) because only one CMOS chip can perform imaging and processing functions that require several chips when CCDs are used. This camera approach is expected to eventually replace film cameras. (Internet, Reprinted from *New York Times,* September 11, 2000)

DARPA Optics Effort Marks Return to Space Research **G-89**
This article describes a DARPA effort entitled The Coherent Communications, Imaging and Targeting program. The project is aimed at producing more efficient systems for tracking satellites from the ground and ground objects from space. It is managed by Dr. David Whelan, director of DARPA's Tactical Technology Office. The work marks a return to space research by DARPA. It is the first DARPA space project since the early 1990s, when opposition from the Congress, industry and the White House caused the agency to focus on other areas. (*Defense News,* July 24, 2000, p. 16)

Darpa Envisions New Supersonic Designs **G-91**
A description of DARPA's plans to develop a quiet supersonic aircraft. Congress has allocated $35 million for this project, over the next 2 years. (*Aviatiuon Week & Space Technology,* August 28, 2000, p. 47)

Board manufacturers show interest and concern over new reliability standards **G-93**

Industry circuit board manufacturers are somewhat concerned about a new standard called Prism (which was discussed at a recent AGED meeting). Prism is expected to replace MIL-HDBK 217 and is much more encouraging about the use of plastic parts. One issue is that industrial concerns will have to pay for the use of Prism whereas MIL-HDBK 217 was available to them free of charge. Prism software costs $1995; free upgrades are available from the World Wide Web. (*Military & Aerospace Electronics,* June 2000, p. 1)

Lockheed Agreement Tests U.S. Policy **G-95**

Lockheed Martin will sell its Aerospace Electronics Systems business, including Sanders, Space Electronics and Communications in Manassas, VA and Fairchild Systems in New York, to BAE for $1.67 billion. According to a Pentagon spokesperson, the DoD will review the transaction "to ensure that U.S. national security interests are properly addressed." (Internet, reprinted from *Washington Post,* July 14, 2000, Page E01)

Trends in China's Semiconductor Industry; Semiconductor Companies in China; Newer Fabs in China (3 articles) **GRECENT-17**

A series of articles from *Semiconductor International* describing status and plans of China's rapidly growing semiconductor industry. Development of semiconductor capabilities is the highest priority for China's Ministry of Information Industries. (*Semiconductor International,* September 2000, p. 134-162)

New Technology Blueprint To Guide Raytheon R&D **G-99**

Raytheon is developing a new technology strategy that seeks a reasonable balance between projects with short- and long-range goals. The article comments that approximately 20% of Raytheon's IR&D funds, totaling $30 million, are spent on long-range technology developments such as GaN MMICs. (*Aviation Week & Space Technology,* August 28, 2000, p. 58)

Sanders Will Give BAE Systems Dominant Role in Airborne EW **G-101**

By purchasing Sanders, BAE will acquire the largest span of advanced electronic warfare technology of any company in the world. Part of that capability is the Sanders' MMIC facility at Nashua, NH. Another part is Sanders' solid-state, multiband laser capability funded by DARPA. (*Aviation Week & Space Technology,* July 31, 2000, p. 74)

Northrop Grumman Chief Renews Aggressive Acquisition Strategy **G-103**

Even though Northrop Grumman lost its bid to acquire Lockheed Martin/Sanders, its CEO, Kent Kresa is continuing to look for other defense electronics companies to take over. Northrop Grumman has one of best balance sheets in that industry, with $300 million of cash and expectancy of an additional $700 million from the sale of its aerostructures business. (*Aviation Week & Space Technology,* August 7, 2000, p. 53)

Update on GaN Technology and Markets **G-105**

A summary of the recent Strategies Unlimited report on GaN markets. Note that the projected market for electronics is tiny compared with that for optoelectronics, even in 2009. (*Compound Semiconductor,* July 2000, p. 14)

Rockwell sue JDS Uniphase over chip patent **G-107**
JDS Uniphase is being sued by Rockwell Technologies. Rockwell claims that JDS used Rockwell's patented metal-organic chemical vapor deposition (MOCVD) process to make semiconductor wafers. (Internet, Posted July 21, 2000, Industry News)

Industry to advise U.S. on tech export reform **G-109**
The Center for Strategic and International Studies (CSIS) will perform an assessment of information technology related export controls and recommend appropriate reform measures. Craig Barrett of Intel and Irving Berger of IBM will serve on the commission. A number of prominent Government officials will also be members of the CSIS study group including Senator John Warner and Senator Jeff Bingaman. (*EE Times,* June 26, 2000, p. 49)

R&D support: the area's tech bonanza **G-111**
An article describing the prominence of the Washington DC area in high tech development activities. (*Potomac Tech Journal,* July 3, 2000, p. 1)

Defense News Top 100 **G-113**
The most recent listing of leading defense contractors by *Defense News.* (*Defense News,* August 14, 2000, p. 17)

Working Group A:

Trends in the Market for GaAs Devices **A-1**
A summary of the current sales and projected market trends for GaAs devices, by Stephen Entwistle of Strategy Analytics. Note that the military market for GaAs devices in 1999 was only 4% of the $1863 million total (~ $75 million). The paper was originally presented at the Key Conference on Compound Semiconductors, held in Key West, FL on March 13 and 14, 2000. (*Compound Semiconductor,* May/June 2000, p. 49)

GaAs IC market to triple to $6B in 2004, firm says **A-5**
Another estimate of the global market for GaAs ICs, published by a market research firm called The Information Network, based in New Tripoli, PA. (*Test & Measurement World,* August 2000, p. 6)

Cascode Connected AlGaN/GaN HEMT's on SiC Substrates **A-7**
Results from Cornell University for a MURI program monitored by Dr. John Zolper. The HEMTs consisted of a 0.25 μm gate length common source device cascode connected to a 0.35μm gate length common gate device. Large signal measurements taken at 4 GHz produced 4W/mm saturated output power (1 watt actual power output) with 36% power added efficiency. The cascode configuration of devices had 7 dB more linear gain and 3 dB more compressed gain than the common source device operated by itself at 4 GHz. (*IEEE Microwave & Guided Wave Letters,* Vol. 10, No. 8, August 2000, p. 316)

High Breakdown GaN HEMT with Overlapping Gate Structure **A-11**
UCSB researchers have developed GaN HEMTs with a voltage breakdown of 570 volts. Gate-drain spacing for the device was 13μm. (*IEEE Electron Device Letters,* Vol. 21, No. 9, September 2000, p 373)

Market Demands Increase For InGaP HBTs and PHEMTs **A-15**

EMCORE has completed the first phase of expansion of its fabrication facility for producing InGaP HBTs and PHEMTs. The additional space will allow up to six additional epitaxial growth systems to be installed which, in turn, approximately doubles production capacity for 4" and 6" diameter wafers. (*Microwaves & RF,* June 2000, p. 26)

Sterling to Develop GaN/SiC HBTs, 4-inch SiC Substrates **A-17**

BMDO has won a $688,000 contract from BMDO to develop GaN/SiC HBTs and another $987,000 contract to develop 4-inch SiC wafers, also from BMDO. The SiC growth contract will be monitored by the Army Research Laboratory. Sterling's partners for the HBT program are Astralux of Boulder, CO and University of Colorado at Boulder. Sterling was recently purchased by Uniroyal. (*Compound Semiconductor,* July 2000, p. 11)

Epitaxial III-nitrides Demonstrated on AlN Substrates **A-17**

A Rensselaer/Crystal IS team has demonstrated high quality, epitaxial growth of AlN and $Al_xGa_{1-x}N$ on AlN substrates. Crystal IS, of Latham NY, has recently won a Phase II SBIR contract from BMDO to grow 50-mm diameter AlN substrates. In addition, it has received a Phase I SBIR from AFRL to increase the growth rate of AlN and a Phase I STTR, from ONR, to improve the fabrication of nitride HFETs on AlN substrates. The latter program is a collaborative effort with Rensselaer and Sensor Electronic Technologies of Latham, NY . (*Compound Semiconductor,* July 2000, p. 11)

Fab Four Address Growing GaAs Markets **A-19**

A description of four new GaAs device fabrication facilities being built by WIN Semiconductors, a newly formed Taiwanese company, Advanced Wireless Semiconductor Company, another Taiwanese company, Nortel Networks and RF Micro Devices. The article also contains information about GaAs fabrication facility remodeling and expansion by Filtronic, Motorola, Alpha Industries, Anadigics, Tyco M/A-COM, Conexant Systems and TriQuint. . (*Compound Semiconductor,* May/June 2000, p. 42)

TriQuint to Purchase Wafer Fabrication Facility **A-23**

TriQuint will be moving from its present location on the Texas Instruments' campus to a facility in Richardson, TX, formerly owned by Micron Technology, Inc. The new TriQuint location will have 48,500 sq. ft. of Class 1 clean room space with an additional 10,000 sq. ft. of Class 100 space and 80,000 sq. ft. of office space. (Internet, News & Analysis @ RF Globalnet, June 2, 2000)

Motorola Semiconductor Completes Six-Inch Conversion of GaAs Fab Three Months Ahead of Schedule **A-25**

Information about Motorola's conversion of its Compound Semiconductor-1 (CS-1) GaAs fabrication facility from processing of 4" diameter wafers to 6" diameter ones in June 2000. It is now the largest GaAs fabrication facility in the world. All of Motorola's GaAs semiconductor devices are fabricated in this facility. It is located in the Phoenix, AZ area. (Internet, Motorola Press Release, June 14, 2000)

Uniroyal Technology Acquires Sterling Semiconductor **A-29**

Uniroyal Technology Corporation has purchased Sterling Semiconductor, a silicon carbide material company, for approximately $36 million. Uniroyal currently produces high brightness

InGaN and AlInGaP LEDs at its plant in Tampa, FL.. (*Compound Semiconductor,* May/June 2000, p. 10)

$13m headed to Raleigh chip firm for market run **A-31**

A spinoff from North Carolina State University, called Nitronix Corp., claims that it has found a better way to produce gallium nitride and (subsequently) make gallium nitride chips for wireless applications. It will be receiving $13 million in new capital from a group of venture capitalists including Southeast Interactive Technology Funds, Alliance Technology Ventures and Vantage Point Venture Partners. (*Potomac Tech Journal,* August 28, 2000, p. 10)

High Power X-Band GaN PA from HRL Labs **A-33**

HRL Laboratories has produced a GaN power amplifier that provides more than 20 watts of power output at X-band. Maximum power added efficiency was 43%, achieved while the device was yielding 21.4 watts of CW output power. Active device layers were produced using molecular beam epitaxy.. (*Compound Semiconductor,* May/June 2000, p. 10)

High Performance Fully Selective Double Recess InAlAs/InGaAs/InP HEMT's **A-35**

20 GHz and 60 GHz results for InP HEMT devices fabricated by Lockheed Martin, Sanders. The double recess devices have 0.12μm gate lengths. At 20 GHz, 65% maximum power added efficiency was achieved with an associated gain of 13.5 dB and at an output power of 185 mW/mm (83 mW). Maximum power output at 20 GHz was 300 mW with 15.6 dB gain and 49% power added efficiency. At 60 GHz, a maximum power added efficiency of 40% was measured with an associated gain of 7.4 dB and power output of 290 mW/mm (130 mW). (*IEEE Electron Device Letters,* Vol. 21, No. 7, July 2000, p. 335)

The Effect of Surface Passivation on the Microwave Characteristics of Undoped AlGaN/GaN HEMT's **A-39**

Cornell University researchers have observed substantial improvement in the performance of AlGaN/GaN HEMT's when a Si_3N_4 passivation layer is applied to their surface. Saturated power density increased from 1 W/mm to 2 W/mm with 15 volts applied to the drain. Power added efficiency increased from 36% to 46%. 4W/mm was achieved with 41% power added efficiency when the drain voltage was increased to 25 volts. All HEMT's were fabricated on sapphire substrates. The 4W/mm result is the highest microwave power density reported to-date for AlGaN/GaN HEMT's fabricated on undoped sapphire substrates. (*IEEE Electron Device Letters,* Vol. 21, No. 6, June 2000, p. 268)

Titanium Hydride Formation in Ti/Pt/Au-Gated InP HEMTs **A-43**

A study by Lockheed-Sanders reveals new information about the effect of hydrogen exposure on GaAs PHEMT and InP HEMT device performance. For HEMTs with Ti/Pt metal layers, titanium hydride, TiH_x, is formed after exposure to hydrogen. This creates a piezoelectric effect. However, a recovery anneal of the structures in N_2 decreases the amount of TiH_x and eliminates most of the deleterious effect. (*IEEE Electron Device Letters,* Vol. 21, No. 9, September 2000, p. 376)

Be Diffusion in InGaAs/InP Heterojunction Bipolar Transistors **A-47**

Recent reliability data from research conducted by Agilent Laboratories (the fabricator of the HBTs), RF Micro Devices and University of Illinois on InGaAs/InP HBTs. Beryllium diffusion was observed when the HBTs were operated under bias stress at elevated temperatures. The

researchers concluded that the diffusion is controllable at lower power densities but "suspect" at higher power densities. They also believe that their data indicates that carbon is a more stable dopant than beryllium. (*IEEE Electron Device Letters,* Vol. 21, No. 7, July 2000, p. 332)

RF design, modeling tools draw crowds at show **A-51**

Commentary about the great interest shown, at the 2000 International Microwave Symposium, about the layout and simulation tools for RF systems introduced at the Symposium exhibits. Companies introducing new CAD tools included Ansoft, Applied Wave Research, Sonnet and Xpedion. The article also synopsizes some new device and IC offerings presented including Analog Devices wideband CDMA chip for use in third-generation cellular systems and Ericcson's use of 25 watt, 2.4-2.5 GHz LDMOS transistors in its cellular basestations. (*EE Times,* July 10, 2000, p. 69)

Silicon Carbide and Gallium Nitride Circuits for Wireless Communications: Why, What and When **A-53**

A paper by Ray Pengelly of Cree, Inc., originally presented at the Key Conference on Compound Semiconductors, describing performance advantages and development status of SiC and GaN devices for wireless communication applications. (*Compound Semiconductor,* May/June 2000, p. 36)

Low-Voltage C-Band SiBJT Single-Chip Receiver MMIC Based on Si 3-D MMIC Technology **A-57**

Another Masterslice™ 3-D MMIC from NTT. This chip provides a complete receiver on a single 1.8mm x 1.8 mm silicon chip. The receiver includes a low-noise amplifier, an image-rejection mixer, and an IF hybrid associated with an IF amplifier. The receiver has a conversion gain of 13.5 dB a noise figure of 5.2 dB and an image rejection ration of almost 31 dB at 5.2 GHz. It has an approximately flat gain characteristic over the range from 4.5 to 6.5 GHz. Power consumption is 115 milliwatts and it operates from a 2 volt collector supply. (*IEEE Microwave & Guided Wave Letters,* Vol 10, No. 6, June 2000, p. 248)

Applications of GaAs ICs to Communications **A-61**

A paper by J. Aiden Higgins of Rockwell Science Center, originally presented at the Key Conference on Compound Semiconductors, describing a number of circuit applications of GaAs ICs for communications. In addition to GaAs-based analog ICs, mixed mode integrated circuits and digital and low power ICs are covered. (*Compound Semiconductor,* May/June 2000, p. 60)

Government systems depend on wireless technologies **A-67**

An article describing the importance of wireless RF communications for agencies throughout the Government. (*RF Design,* July 2000, p. 40)

A Megawatt Power Millimeter-Wave Phased Array Radar **A-73**

No solid state in this one. A description of the Russian multi-megawatt "Ruza" radar. The system uses a large mechanically steered, millimeter-wave phased array antenna and gyroklystrons as its power source. (*IEEE AES Magazine,* July 2000, p. 25)

MEMS in CMOS--21st century RF and microwave applications **A-81**
A description of the use of RF MEMS components such as inductors to reduce the size of wireless communication systems. (*RF Design,* July 2000, p. 32)

Through the Left-Handed Looking Glass **A-85**
More information on a novel photonic material developed by University of California researchers. The material, constructed from copper rings and wires, reverses many physical properties ordinarily expected from electromagnetic radiation. (*Photonics Spectra,* June 2000, p. 23)

Working Group B:

The Challenges of System on a Chip **B-1**
A discussion of the technical and economic challenges for developing system on a chip architectures. (*ElectronicPackaging & Production,* May 2000, p. 18)

Post Moore's Law, systems seen taking driver's seat **B-7**
Representatives from IBM, Hewlett-Packard and other companies at a meeting called Beyond Silicon 2000 were unanimous in predicting the end of Moore's Law advances in silicon technology, approximately 10 years from now. Future advances are likely to focus on interconnection technologies. Joel Birnbaum of Hewlett-Packard says, "We see a continuing role for silicon technology as the printed-circuit board for future molecular-based systems." (*EE Times,* June 26, 2000, p. 83)

Can Anything Stop The Transistor? **B-9**
A discussion of future transistor trends by Dr. Paul Peercy, dean of engineering at the University of Wisconsin, Madison, WI. (*The Industrial Physicist,* June 2000, p. 18)

World Chip Sales Total $14.9B in March **B-13**
A March 2000 global sales report for semiconductors from Semiconductor Industry Association. (*HDI,* June 2000, p. 12)

SIA says chip market boom will continue through 2003 **B-15**
The Semiconductor Industry Association is predicting a 31% growth rate for the semiconductor market in 2000 and an average growth rate of more than 20% for the next three years. (*EE Times,* June 19, 2000, p. 58)

Analysts: Chips headed for a fall **B-17**
In apparent disagreement with the article immediately above, some industry analysts, such as Bill McClean, president of IC Insights, Inc., are predicting that the $200 billion semiconductor market will enter a period of price-plummeting overcapacity and suffer a sharp downturn beginning in 2001 or early 2002. (*EE Times,* July 10, 2000, p. 1)

Philips buys IBM fab, looks to double BiCMOS capacity; Philips Semiconductors Acquires 8-in. Wafer Fab (2 articles) **B-21**
Philips has purchased the 8" IBM Si fabrication facility in East Fishkill, NY. It plans to make 0.25μm and 0.35μm minimum feature size devices there, primarily for communications and consumer markets. The current capacity of the factory is 250,000 CMOS wafers per year. Philips is buying new equipment to add the BiCMOS capability. The fab will continue to act as

a foundry for IBM for products already in production by IBM through 2002. (*EE Times,* June 26, 2000, p. 20; Internet, News & Analysis @ RF Globalnet, June 21, 2000)

Lucent, Chartered to invest $700M in process R&D **B-25**
Another example of teaming between digital integrated circuit producers to share the high costs of developing advanced semiconductor processes. This partnership, between Singapore's Chartered Semiconductor Manufacturing and Lucent Technologies' Microelectronics Group, will invest $700 million during the next three years to develop advanced processes for communications semiconductors. Three process generations will be addressed, with minimum feature sizes starting at 0.13µm and decreasing to 0.08µm. The article contains a summary chart listing other partnerships between chip makers, their process development goals and targeted application areas. (*EE Times,* August14, 2000, p. 4)

Intel expands on 300-mm fab plans **B-27**
Intel has announced plans for a 300-mm IC fabrication facility in Rio Rancho, NM. The plant is expected to cost $2 billion to build and equip; it will be Intel's first 300-mm facility. The plant will make microprocessors with 0.13µm minimum feature sizes and use copper interconnection technology. (*EE Times,* May 29, 2000, p. 8)

UMC builds 2-Mbyte SRAMs in 0.13 micron **B-29**
2 Mbyte SRAM chips have been produced by United Microelectronics Corporation of Taiwan using 0.13µm process technology. The chips have copper interconnects and gate lengths of 0.1µm. Pilot production will begin later this year. UMC plans to invest $12 billion in capital expenditures during the next four years. (*EE Times,* May 22, 2000, p. 40)

Chip makers see 0.10-micron within their grasp **B-31**
Papers presented at the 2000 Symposium on VLSI technology indicated that 0.10 µm minimum feature size integrated circuits will be available within a few years. Intel indicates readiness in about two and a half years. (*EE Times,* June 19, 2000, p. 6)

IBM says yea, Intel nay, to silicon-on-insulator **B-33**
IBM and Intel disagree on the importance of silicon-on-insulator technology for future digital integrated circuits. IBM plans to emphasize use of silicon-on-insulator for its future generations of digital integrated circuits and will describe their 0.13µm processing techniques for both silicon-on-insulator and conventional bulk silicon at the VLSI Technology Symposium in Honolulu. Intel however, states that 0.1µm minimum feature size devices fabricated on SOI have considerably poorer performance gain compared with similar devices fabricated on bulk silicon. In addition, an Intel research has stated that the higher cost of SOI wafers makes their use impractical for high volume manufacturers. (*EE Times,* May 22, 2000, p. 55)

SOI divide splits CPU vendors (please see above article also) **B-35**
AMD, TI and Motorola are in agreement with IBM that silicon-on-insulator technology will provide performance gains compared with bulk silicon. Some believe that this performance improvement will be as much as 20%. Motorola plans to use a SOI process technology with 0.18µm design rules and then transition to 0.13µm design rules for its new Power PC processor. (*EE Times,* June 19, 2000, p. 1)

IBM spins two 130-nm processes: SOI, bulk CMOS **B-37**

IBM is covering all bases by introducing both a SOI process and a triple-oxide bulk CMOS process, compatible with embedded DRAM and analog circuits. The SOI process is expected to provide the highest performance. IBM believes that it will be more difficult to scale the performance of bulk CMOS for design rules of 0.10μm or less. (*EE Times,* June 26, 2000, p. 30)

Photoresist tech on the move **B-39**

Hyundai Electronics has a new argon fluoride photoresist technology that it believes will be useful for circuit widths as small as 0.09 μm. TI and Intel have begun testing this photoresist. (*EE Times,* June 26, 2000, p. 44)

Partnership Approved For Radiation-Hardening Commercial Microelectronics **B-41**

Space Electronics, Inc. has signed a strategic partnership with U.S. Semiconductor to commercialize a wafer-thinning process that provides radiation hardening of commercial microelectronics. The process is called RHI-NO™. (*Microwaves & RF,* May 2000, p. 27)

Consensus sought on next-gen litho **B-43**

A discussion of progress on International Sematech efforts to demonstrate the viability of 157 nanometer lithography technology. It is concerned with meeting a 2003 deadline to demonstrate the feasibility of 157-nm lithography and its cost effectiveness. The key problem areas are resists, pellicles and masks. Currently, International Sematech is directing its resources toward solving problems in these technology areas. (*EE Times,* July 10, 2000, p. 55)

Global effort required to realize 157-nm litho **B-45**

A discussion of the need for a cooperative global effort to realize 157 nm lithographic equipment and associated products (e.g., masks and resists). The article is written by Wally Carpenter, an IBM assignee to SEMATECH and mask strategy manager for International SEMATECH. (*EE Times,* August 7, 2000, p. 49)

Optical barrier falls for UV lithography **B-47**

International SEMATECH has determined that it will be possible to develop a process to produce ICs with minimum feature sizes as small as 0.07μm, using 157 nm wavelength light from a 6 watt fluorine laser. (*Electronic Products,* August 2000, p. 24)

U.S. official challenges Infineon's litho deal **B-49**

William Reinsch, commerce undersecretary of export administration, has told Ernest Moniz, undersecretary of energy, that he is concerned about the decision to allow Infineon, a foreign chip maker into the EUV consortium as a partner. In particular, he believes that the $10 million Infineon is contributing to the consortium is an inadequate amount for it to pay to gain access to this advanced EUV technology. (*EE Times,* June 5, 2000, p. 1)

Semiconductor manufacturers join 157 nm lithography initiative **B-53**

Advanced Micro Devices, Infineon, Motorola and six other companies are joining a 157 nanometer lithography technology program. The initiative was started, in mid-1999, by ASML, a Dutch microlithography company. (Internet, Optics. Org, Industry News, Posted July 21, 2000)

Litho system ready by spring? **B-55**

Optimism is growing that EUV lithography will become practical circa 2005. A near-term goal is to have the optics and illumination subsystems combined by this fall and to have a working EUV lithography system ready for assessment by next spring. Commercial systems are expected to follow with high volume chip fabrication using this equipment beginning in 2005. (*EE Times,* June 5, 2000, p. 202)

Timing at issue for shift to 157-nm lithography **B-57**

An article discussing timetable possibilities for the introduction of 157 nm lithography tools into production IC lines. (*EE Times,* May 22, 2000, p. 30)

Two Experts on the Frontiers of Lithography **B-59**

A lithography-oriented interview, by *Photonics Spectra* editor Dr. Milton Chang, of John Carruthers, Director of components research at Intel, and James Glaze, executive director of the Virtual National Laboratory headquartered at Lawrence Livermore National Laboratory. (*Photonics Spectra,* June 2000, p. 82

Free Silicon (Almost)! The Package Now Counts **B-61**

A discussion of the importance of packaging for preserving the high performance of integrated circuit chips. (*HDI,* June 2000, p. 14)

Ultrafine-Line HDI Technology at Georgia Tech's PRC **B-63**

A discussion of leading edge packaging technology being developed at Georgia Tech's Packaging Research Center. Georgia Tech. is developing 3-dimensional packaging structures that incorporate embedded passive components and use low-loss dielectric filled/stacked microvias. (*HDI,* August 2000, p. 20)

Enhanced Substrates for High-Performance Memory **B-67**

A discussion of advanced packaging techniques for high performance memory chips. (*HDI,* August 2000, p. 26)

IBM Unveils World's Fastest Computer **B-71**

IBM has produced a computer that will be used by the U.S. Government to simulate nuclear weapons tests. This computer has 8,192 copper metallization microprocessors, takes up floor space equivalent to two basketball courts, weighs as much as 17 adult elephants and will be sold to DOE for $110 million. (Internet, Reuters, June 29, 2000)

Largest quantum computer does code cracking **B-75**

Another IBM computer breakthrough; a 5 bit computer on a single molecule. The five fluorine atoms in the molecule represent quantum bits. The computer is the first one that can solve a difficult code-cracking problem, called the order-finding problem, in a single step. (*EE Times,* August 28, 2000, p. 83)

The New MEMS and Their Killer Apps **B-77**

A summary by *Sensors* Magazine of potential new applications for MEMS, projected compound annual growth rates of world-wide market shipments of MEMS by application area and, perhaps most interesting, an update of the "MEMS Report Card". In 1998, MEMS R&D was given a

grade of "A" in R&D by *Sensors*, and grades of "C" or "Incomplete" for every other category (marketing, market research, design for manufacturing, established infrastructure, industry association, standards etc.) for an overall grade of "C". Two years later it has improved its position in every category to receive an overall grade of "B". Its remaining weak points are profitability, management expertise and marketing. (*Sensors,* July 2000, p. 4)

MEMS: following in the footsteps of the Internet? **B-81**

Commentary by John Rhea of *Military & Aerospace Electronics,* that offers a somewhat different viewpoint from that of the above article. Mr. Rhea indicates that in contrast with the Internet, which represents a "market pull" technology, MEMS can be characterized as a "technology push" development. The article states that DARPA is the strongest proponent of the use of MEMS for military applications but indicates that it must get military users to embrace this technology. According to the article, "Unlike the Internet, which rapidly generated its own momentum, MEMS remains a technology sitting on the shelf waiting for the big rush of customers." (*Military & Aerospace Electronics,* September 2000, p. 8)

MEMS industry shakes down into 'Big 4' **B-83**

A discussion of the consolidation of the MEMS industry. Four companies are dominating MEMS fabrication for optical switching and other communication applications. Two of these companies are Canadian--Nortel Corporation and JDS Uniphase. The others are Lucent and Corning. (*Military & Aerospace Electronics,* September 2000, p. 1)

MEMS-based integration advances digital isolation **B-85**

Analog Devices, Inc. is using a new technique to install MEMS structures from a specialized fabrication plant on top of standard semiconductor wafers produced at a different facility. The technology is called *μm*Isolation. It consists of an insulating layer, separating a micromachined transmission coil from an underlying second coil that is part of a receiver chip. Interconnects are made between the MEMS superstructure and the underlying semiconductor wafer. The combined structure provides an isolation capability that enables a new class of products with increased embedded isolation. The first of these is a family of high speed digital isolators. Future devices will be relays, data converters and transformers. (*Electronic Products,* August 2000, p. 23)

Sandia Expands Envelope of MEMS Devices **B-87**

A summary by *Aviation Week & Space Technology* of MEMS developments at Sandia and a discussion of the use of Sandia MEMS micromirror technology in the next generation of NASA's Space Telescope. (*Aviation Week & Space Technology,* June 12, 2000, p. 57)

Sandia National Laboratories' Researchers ... **B-89**

More MEMS news from Sandia. Its researchers have produced microfluidic devices using a process compatible with conventional semiconductor batch-processing tools. (*Aviation Week & Space Technology,* July 17, 2000, p. 65)

CVD tungsten extends MEMS lifetime by order of magnitude **B-91**

An additional article about MEMS developments at Sandia. Sandia researchers have found that a CVD coating of tungsten results in an increase in the lifetime of MEMS devices of

approximately an order of magnitude. They have also found that use of CVD tungsten can easily be incorporated into their MEMS process flow. (*Solid State Technology,* July 2000, p. 38)

Magnetic actuation may boost 3-D MEMS output **B-93**

University of Illinois researchers have developed a magnetic actuator that allows self-assembly of 3-D MEMS devices in a production environment. They claim that it would be a very useful tool to add to the Sandia National Laboratories 3-D MEMS processing sequence that Sandia is currently licensing to foundries. (*EE Times,* May 22, 2000, p. 91)

Wafer-Level Aligned Bonding for Interconnects and MEMS **B-95**

A discussion of the advantages and disadvantages of various substrate-to-substrate alignment techniques and a report on a new approach to wafer-to-wafer alignment. (*HDI,* June 2000, p. 22)

MEMS-based inductors yield single-chip RF **B-99**

Memscap SA, a French-owned company, has produced and is selling a family of inductors based on MEMS. The components are expected to be used in wireless applications. MEMScap also licenses its manufacturing processes for placing its MEMS-based inductors on top of existing silicon circuitry. A copper-on-insulator process is used with flip-chip assembly. (*EE Times,* June 26, 2000, p. 36)

MEMS Packaging Solutions Open New Markets **B-101**

A description of various possible approaches for packaging MEMS and MOEMS devices including some of the problems that must be dealt with. (*Electronics Packaging & Production,* June 2000, p. 49)

Nanotechnology Extending Materials Science Frontier **B-109**

A report on the development of synthetic materials for use in developing electronic structures with nanoscale dimensions. (*Aviation Week & Space Technology,* September 4, 2000, p. 89)

Quantum transistors: toward nanoelectronics **B-111**

A review article from *IEEE Spectrum* describing progress on several types of quantum transistors being developed at various laboratories. (*IEEE Spectrum,* September 2000, p. 46)

DNA drives micromotor **B-117**

Lucent Technologies has developed a tiny motor built entirely from DNA. The motor and the fuel used to power it were both created from DNA. (*EE Times,* August 28, 2000, p. 83)

News from The 15th Annual Battery Conference on Applications and Advances **B-119**

A report from the 15th Annual Battery Conference on Applications and Advances on new battery developments and applications. In particular, the article states that the Army's new "land warrior" will need a hybrid battery combination of a zinc-air battery plus a lead-acid battery to supply pulse loads. There is also a brief discussion of "charge management" for extending battery life. (*IEEE AES Magazine,* June 2000, p. 25)

Smart devices take military and aerospace power to the next level **B-127**

A discussion of the ONR Power Electronics Building Blocks Program (PEBB) and its efforts to produce "smart power" circuits, *i.e.,* circuits that provide efficient, fast and ubiquitous control of

power distribution and consumption. PEBBs are power processors that can change a particular power input to another desired combination of voltage, current and frequency output. PEBBs sense what they are connected to and automatically perform the necessary electrical conversion. The article contains an interview with Albert Tucker, Division Director of ONR's Mechanical and Electrical Systems Division. (*Military & Aerospace Electronics,* July 2000, p. 21)

DARPA grant seeks alternative ways to manage processors' power **B-133**
Northwestern University has been awarded a $2 million grant from DARPA to develop new ways for minimizing power consumption of computers. (*EE Times,* August 21, 2000, p. 36)

Spectrolab sets new solar-cell record **B-135**
A new conversion efficiency record of 29% has been set for converting solar power into spacecraft power by Spectrolab of Sylmar, CA. The same company has produced Earth-based solar cells with a maximum conversion efficiency of 32.3%. (Internet, Optics. Org Industry News, Posted July 21, 2000)

Working Group C:

A Roadmap for Optoelectronic Interconnects for Integration **C-1**
A paper based on European technology developments that employ III-V optoelectronics as interconnects for CMOS devices. The work is from the Advanced Research Initiative in Microelectronics which is funded by the European Union. (*Compound Semiconductor,* May/June 2000, p. 74)

Fiber-Optics Firm To Swallow Rival **C-7**
JDS Uniphase Corporation plans to buy SDL, Inc. for approximately $41 billion in stock. Both companies make equipment designed to increase the speed and capacity of fiber-optic cables for communications. (*The Washington Post,* July 11, 2000, p. E1)

The dawn of organic electronics **C-9**
An overview of the use of organic materials to produce electronic devices, particularly organic light-emitting devices (OLEDs), from *IEEE Spectrum* magazine. (*IEEE Spectrum,* August 2000, p. 29)

DARPA focuses on organic LEDs in new effort to improve military displays **C-15**
A review of work by Planar Systems, Inc., under its $6 million contract from DARPA, to develop organic LEDs for use in military applications. The article also reviews the history of OLED development and discusses a parallel $1 million DARPA program with Universal Display Corp. of Ewing, NJ aimed at demonstrating quarter-VGA format flexible OLEDs. (*Military & Aerospace Electronics,* August 2000, p. 3)

The Technology Is Pushing -- But Will the Market Pull? **C-17**
A discussion of projected markets for microdisplays. The author concludes that there are two broad application categories for these displays, projection and personal viewers. For the former, market share will depend upon microdisplays achieving price/performance ratios that are superior to those of their entrenched competition. For the latter, the biggest challenge will be market acceptance. (*Information Display,* July 2000, p. 14)

Microdisplays promise big profits for vendors **C-23**

Vendors at the Society for Information Display (SID) conference, recently held in Long Beach, CA, expect as many as 1 million liquid-crystal-on-silicon (LcoS) displays, with diameters of 1 inch or less, to be shipped next year. A leader in this technology is Kopin Corporation which expected to ship its millionth display in June 2000. However, there are a number of other U.S. and Asian companies that are strong competitors of Kopin. (*EE Times,* June 12, 2000, p. 49)

CMOS imagers dial up a market **C-25**

A potentially huge market for CMOS imaging devices has attracted the attention of manufacturers such as Photobit Corporation. It is projected that by 2004, 20-50% of mobile telephone handsets will have embedded cameras. STMicroelectronics, a French company, plans to ship its first-generation CMOS sensor camera module next month to OEM's in Japan. (*EE Times,* September 11, 2000, p. 1)

Raytheon readies new class of micro infrared cameras **C-29**

This fall, Raytheon will be selling a low-power micro infrared camera (MIRC) that uses a 120 x 160 pixel focal plane array of amorphous-silicon microbolometers. (*Military & Aerospace Electronics,* September 2000, p. 12)

LCoS -- Microdisplay Technology and Applications **C-31**

A progress report on liquid-crystal-on-silicon (LCoS) display technology. LCoS devices ranging from 320 x 240 pixels to 2048 x 2048 pixels have been fabricated and demonstrated in products or prototype systems. (*Information Display,* July 2000, p. 20)

Manufacturing LCoS Microdisplays **C-35**

A discussion of the viability of U.S. fabrication of LCoS microdisplays by Michael Stefanov, Chief Technical Officer of Hana Microdisplay Technologies, Inc. (HMTI). HMTI is currently building a high-volume LCoS fabrication facility in Twinsburg, Ohio. (*Information Display,* July 2000, p. 24)

Microvision Demonstrates Miniature Display Based on Cree LEDs **C-39**

Cree LEDs are being used in Microvision Retinal Displays to create an impression by viewers that they are seeing a full-size computer or television screen at arm's length. Cree LEDs are placed on three sides of a miniature optical cube. Light is modulated at very high speeds and scanned by tiny vibrating mirrors through a compact lens into the viewer's eye. Alignment tolerances were sufficiently large to provide optimism that the systems can be manufactured in high volumes with high yields. (*Compound Semiconductor,* July 2000, p. 19)

U.S. Army To Test Microvision Displays; Microvision displays to be part of virtual cockpit (2 articles) **C-41**

Microvision, Inc. has been given a $600,000 addition to its $7.8 million Army contract, awarded to produce helmet-mounted displays that make use of retinal scanning display technology. The additional money will be used to produce another full-color helmet mounted display for the Virtual Cockpit Optimization Program. (*Defense News,* August 28, 2000, p. 18; *Military & Aerospace Electronics,* September 2000, p. 30)

Motorola scales back its FED operation **C-43**

Motorola has once again decided to defer commercializing its field emission display (FED) technology. This was announced at the recent Society for Information Display (SID) Conference. A 275,000 square foot plant, built as a FED production facility in 1997 will be made available for other uses by Motorola. The investment in this plant has been estimated at $350 million. Other companies that have either abandoned FED production or deferred it include Coloray, FED Corporation, Micron Technology, Raytheon and Texas Instruments. Only Candescent Technologies demonstrated prototype displays at the SID Conference. (*EE Times,* May 22, 2000, p. 8)

Printable Large-Area FEDs **C-45**

A discussion of the possibility of using printed field-emission displays to produce cost-effective 20-40 inch diagonal displays. A number of printed FED and FED-like devices have been fabricated by Samsung and Canon. Another company, Printable Field Emitters (PFE), Ltd. in England is also working toward affordable large diameter FED displays. (*Information Display,* June 2000, p. 14)

Plastic LCDs to Roll? **C-49**

A discussion of Polaroid's collaborative efforts with ColorLink, Inc. to produce LCD displays on roll-to-roll equipment. The approach uses three layers of controllable liquid-crystal cells with intermediate coated-polymer LC retarder stacks to provide full-color pixels. (*Information Display,* July 2000, p. 28)

Strong Growth Forecast for Major Laser Markets **C-53**

Information from the latest Strategies Unlimited forecast for semiconductor laser markets. Strategies Unlimited expects the worldwide market for laser diodes to reach $5.35 billion in 2004, up from $1.95 billion in 1999. Major applications include telecommunication networks and DVD video players. (*Compound Semiconductor,* July 2000, p. 30)

Panel Supports Funding of Laser Weapons **C-55**

More information about the laser weapons panel chaired by Dr. Delores Etter, Deputy DDR&E. The committee has recommended that the DoD increase funding for high-energy laser research. (*Photonics Spectra,* June 2000, p 85)

U.S. Laser-Weapon Programs Face Uncertain Future **C-57**

According to Lt. Gen. John Costello, head of the Army Space and Missile Defense Command, the next generation of weapons might be more effective if they fired lasers rather than traditional rounds of ammunition. General Costello's command runs the Tactical High Energy Laser (THEL) program and the High Energy Laser Systems Test Facility at White Sands, NM. THEL is being developed to shoot down short-range rockets. (*Defense News,* July 31, 2000, p. 16)

Laser projects benefit from Congressional overrides **C-59**

Congress has rejected plans by the Air Force to cut back on its work on the Airborne Laser project. It has given the Air Force additional funding for this project, $234 million, and prohibited it from using this money for any other project. In addition, Congress included $15 million for the Tactical High Energy Laser (THEL) project. (*Laser Focus World,* September 2000, p. 77)

First electrically pumped organic laser; Bell Labs shows electrically powered organic laser; Organic laser is electrically pumped (3 articles) **C-61**

The first electrically powered organic laser has been produced by Bell Labs scientists. Part of the excitement of producing an organic laser is that it could be less expensive to manufacture than conventional semiconductor lasers. The laser is produced from tetracene and light generated is yellow-green in color. (Internet, Optics.Org Industry News, Posted August 4, 2000; *EE Times,* August 7, 2000, p. 65; *Laser Focus World,* September 2000, p. 19)

Diode-pump lasers key to enabling worldwide optical networking **C-67**

An article that describes the importance of designing diode pump lasers into amplifiers for dense wavelength-division multiplexing (DWDM) systems because of the reliability advantages they provide from operating at relatively power. (*Lightwave,* June 2000, p. 168)

Surface-emitting lasers aim for mid range nets **C-69**

VCSELs are expected to be used in mid-range "neighborhood" fiber optic networks. Sandia and Cielo Communications Inc. have teamed to build 1.3μm VCSELs grown on GaAs for this and other applications. (*EE Times,* June 26, 2000, p. 83)

VCSEL emitting at 1.6μm is suitable for mass production **C-71**

A company called Bandwidth 9 in Fremont, CA has produced the first monolithic long-wavelength VCSEL. The VCSEL transmitted data over 50 km of single-mode fiber without optical amplification at 2.5 Gbit/second with a bit-error rate of less than 1×10^{-9}. The optical power received at the end of the fiber was -28 dBm. (*Laser Focus World,* June 2000, p. 9)

EMCORE"S Optical Device Div., ... **C-73**

Emcore has produced new 850 nanometer VCSEL arrays: one is a 1 x 4 array that can transmit at speeds up to 10 GB/sec; the other is a 1 x 12 array capable of transmitting at speeds up to 30 GB/sec. It has also produced high-speed photodetector arrays from GaAs with data rates as high as 3.125 GB/sec. (*Aviation Week & Space Technology,* September 4, 2000, p. 88)

SBR-based mode-locked laser emits more than 50 W **C-75**

Spectra-Physics engineers have produced a laser system that has a quasi-continuous-wave power output of more than 50 watts. The output is an 80 MHz flow of ultrafast pulses with a pulse width of approximately 10 picoseconds. The technology was originally developed by Lucent and licensed to Spectra-Physics. (*Laser Focus World,* June 2000, p. 13)

DARPA, Air Force search for a better way to steer military lasers **C-77**

A discussion of the DARPA funded, Air Force managed, Steered Agile Beams (STAB) program. The program's objective is to develop a new, efficiency laser beam-steering mechanism. Potential program benefits include the possibility of scanning a laser beam over more than 45 degrees, eye-safe laser operation, rapid acquisition of laser receivers, the ability to focus a laser designator on mobile targets from 2-3 kilometers away, correction for atmospheric degradation and covert optical data communications and target-designation capabilities. (*Military & Aerospace Electronics,* August 2000, p. 19)

Optical Systems Look to 10 Gb/s And Beyond **C-79**

A report on the latest applications of fiber-optic technology to communications systems with a discussion of some of the newest components developed by various vendors. (*Microwaves & RF*, July 2000, p. 29)

Polymer films promise high-speed computing **C-83**

Researchers at Dortmund University in Germany have developed a new method to realize optical interconnects for high-speed communication between processors. The method involves integrating polymer foil-based optical waveguides into standard printed circuit boards. (Internet, Optics.Org Industry News, Posted September 8, 2000)

Optical bandgap material created **C-85**

Kyoto University researchers have produced a material that can control light in a manner similar to the way that semiconductors use electrons. If materials like this prove to be practical, it may be possible to produce all-optical integrated circuits. The material is an unusual configuration of specially etched gallium arsenide wafers. (*EE Times*, August 28, 2000, p. 83)

Photons can't do it all--yet **C-87**

A commentary by Stephen M. Hardy, Editorial Director and Associate Publisher of *Lightwave*, reminding readers that many types of electronic circuits still play an important role in conjunction with photonics for optical systems. (*Lightwave*, June 2000, p. 23)

Electronics, photonics vie for optical-net switching **C-89**

Reports from the 45th International Symposium on Optical Science, Engineering and Instrumentation. Silicon-based electronics is far ahead of photonic computing in both logic processing and mass data storage. However, advances in photonic interconnection technology are of increasing interest and importance. (*EE Times*, August 14, 2000, p. 75)

MEMS display technology gets nod from Sony **C-91**

Sony has licensed a MEMS technology called the Grating Light Valve from Silicon Light Machines, a California company. It is expected to initially be used in projectors for business applications and later for consumer applications like home theaters. The technology is somewhat similar to TI's Digital Micromirror Devices but uses tiny ribbons rather than tilting mirrors. The devices are diffractive rather than reflective ones. GLV components generate a 1,080 pixel line which is scanned at a rate of 60 frames per second to create an image of 1920 x 1080 pixels. (*EE Times*, July 17, 2000, p. 1)

Researchers Find New Uses for an Old Semiconductor **C-93**

Indium gallium arsenide nitride is being reconsidered for use in telecommunications lasers and in solar cells for satellites. The use of nitrogen will allow tailoring of electrical and optical properties to those required for a particular application. (*Photonics Spectra*, June 2000, p. 38)

APPENDIX F

Acronyms and Abbreviations

3-D .... Three Dimensional

a-Si .... Amorphous Silicon

A/C .... Aircraft

AAV .... Amphibious Armored Vehicle

ABIS .... Advanced Battlespace Information System

ABL .... Airborne Laser

ACT .... Advanced Concept Technology

ACTD .... Advanced Concept Technology Demonstration

ACTS .... Advanced Communications Technology Satellite

ADC .... Analog to Digital Converter

ADM .... Advanced Development Model

ADSAM .... Air Directed Surface to Air Missile

AFRL .... Air Force Research Laboratory

AGED .... Advisory Group on Electron Devices

AGTFT .... Antijam GPS Technology Flight Test

AIED .... Advanced Integrated Electronics Defense

AIEWS .... Advanced Integrated Electronic Warfare System

AIRE .... Advanced Intermediate Representation with Extendibility

ALERT .... Air/Land Enhanced Reconnaissance and Targeting

ALI .... Alpha Lamp Integration

ALISS .... Advanced Lightweight Influence Sweep System

AlSb .... Aluminum Antimonide

AlN .... Aluminum Nitride

AMCM .... Airborne Mine Countermine

AMEL .... Active Matrix Electro Luminescent

AMIE .... Advanced Multiplex Interface Element

AMLCD .... Active Matrix Liquid Crystal Display

ANVIS/HUD ...... Aviator's Night Vision System/Heads Up Display

AOC .... Airborne Operations Command

AOSN.................. Autonomous Ocean Sampling Network
APATCH .... Commercial Code for Computational Electromagnetics
ARL .... Army Research Laboratory
ASEM .... Application Specific Electronic Module
ASIC .... Application Specific Integrated Circuit
ASMD................. Anti-Ship Missile Defense
ASTAMIDS .... Airborne Standoff Minefield Detection System
ATACMS............ Advanced Tactical Missile System
ATD .... Advanced Technology Demonstration
ATE..................... Automated Test Equipment
ATIRCM............. Advanced Threat Infrared Counter Measures
ATP..................... Acquisition Pointing and Tracking
ATR .... Automatic Target Recognition
ATRJ................... Advanced Threat Radar Jammer
AUV.................... Autonomous Underwater Vehicle
AWACS .... Airborne Warning and Control System
AWFT .... Anti-Materiel Warhead Flight Test
BADD .... Battlefield Awareness and Data Dissemination
BAMB................. Bending Annular Missile Body
BAT .... Brilliant Anti-Tank
BBO .... Barium Bismuth Oxide
BC^2A................... Bosnia Command and Control Augmentation
BCIS .... Battlefield Combat Identification System
BCP..................... Best Commercial Practices
BDA.................... Battle Damage Assessment
BGA.................... Ball Grid Array
BIST.................... Built In Self Test
BIT...................... Built In Test
BJT...................... Bipolar Junction Transistor
BMDO .... Ballistic Missile Defense Organization
BRP..................... Basic Research Plan
BW...................... Bandwidth

BW .... Biological Warfare

BWD .... Body Worn Display

C&C .... Cut and Cover

C-E .... Communications-Electronics

C^2 .... Command and Control

C^2I .... Command Control and Intelligence

C^3 .... Command Control and Communications

C^3I .... Command Control Communications and Intelligence

C^4 .... Command Control Communications and Computers

C^4I .... Command Control Communications Computers and Intelligence

C^4ISR .... Command Control Communications Computers Intelligence Surveillance and Reconnaissance

CAD .... Computer Aided Design

CAE .... Computer Aided Engineering

CAS .... Close Air Support

CASTFOREM .... Combined Arms Support Task Force Evaluation Model

CATOX .... Catalytic Oxidation

CATV .... Cable TV

CB .... Chemical and Biological

CC&D .... Camouflage Concealment and Deception

CCD .... Charge Coupled Device

CDR .... Critical Design Review

CEC .... Cooperative Engagement Capability

CECOM .... U.S. Army Communications Electronics Command

CID .... Combat Identification

CIMINT .... Communication Intelligence

CIMMD .... Close in Man Portable Mine Detector

CINC .... Commander in Chief

CJTF .... Commander Joint Task Force

CM .... Countermeasures

CMD .... Cruise Missile Defense

CMOS .... Complementary Metal Oxide Semiconductor

COA .... Course of Action

COB .... Chip on Board

COBRA............... Coastal Battlefield Reconnaissance and Analysis

COIL .... Chemical Oxygen Iodine Laser

CONUS .... Continental United States

COTS .... Commercial Off the Shelf

CPRC .... Counterproliferation Program Review Committee

CRT..................... Cathode Ray Tube

CSP .... Chip Scale Packaging

CSS .... Combat Service Support

CTF .... Common Technical Framework

CVD .... Chemical Vapor Disposition

CW .... Continuous Wave

CW .... Chemical Warfare

DAC .... Digital to Analog Converter

DARPA............... Defense Advanced Research Projects Agency

DBBL.................. Dismounted Battlespace Battle Lab

DBF..................... Digital Beamforming

DBS..................... Direct Broadcast Satellite

DC....................... Direct Current

DCOR .... Defense Committee on Research

DDR&E .... Director Defense Research and Engineering

DF .... Direction Finding

DIA .... Defense Intelligence Agency

DII....................... Defense Information Infrastructure

DIRCM .... Directed Infrared Countermeasure

DISC/DIAL......... Differential Scattering/Differential Absorption of Light

DLA .... Defense Logistics Agency

DMD .... Deformable Mirror Device

DMP.................... High Density Microwave Package

DMSO................. Defense Modeling and Simulation Office

DoD..................... Department of Defense

DOE .... Department of Energy

DOE .... Department of Energy

DPSS .... Diode Pumped Solid State

DRAM .... Dynamic Random Access Memory

DRB .... Division Ready Brigade

DRFM .... Digital Radio Frequency Memory

DSO .... Defense Sciences Office

DSP .... Digital Signal Process

DSP .... Defense Support Program

DSTAG .... Defense Science and Technology Advisory Group

DSWA .... Defense Special Weapons Agency

DTAP .... Defense Technology Area Plan

DTO .... Defense Technology Objective

DUSD .... Deputy Under Secretary of Defense

DUSD(AT) .... Deputy Under Secretary of Defense (Advanced Technology)

DUT .... Device Under Test

DVE .... Driver's Viewer Enhancer

EA .... Electronic Attack

EC .... Electronic Combat

ECM .... Electronic Countermeasures

EFOG .... Enhanced Fiber Optic Guided

EFOG-M .... Enhanced Fiber Optic Guided Missile

EHF .... Extremely High Frequency (30-300GHz, but slang includes 20GHz)

EIA/IEC .... Electronics Industry Association/International Electrotechnical Committee

EIT .... Electronic Integration Technology

EL .... Electro-Luminescent

ELF .... Extremely Low Frequency

ELINT .... Electronic Intelligence

EM .... Electromagnetic

EMD .... Engineering Manufacturing Deployment

EMD .... Engineering Model Development

EMI .... Electromagnetic Interference

EN-TD .... Explosive Neutralization Technology Demonstration

EO .... Electro-Optic

EOD/NSW .... Explosive Ordnance Demolition/Naval Special Warfare

EP .... Electronic Protection

EP&I .... Electronic Packaging and Interconnect

EPA .... Environmental Protection Agency

EPLRS .... Enhanced Position Location and Reporting System

ERASER .... Enhanced Recognition and Sensing LADAR

ES .... Electronic Support

ESM .... Electronic Support Measures

ESSM .... Evolved Sea Sparrow Missile System

ETL .... Embedded Transmission Line

EW .... Electronic Warfare

EXCOM .... Executive Committee

FAC .... Forward Air Controller

FAP .... Forward Area Plan

FAR .... False Alarm Rate

FDA .... Food and Drug Administration

FED .... Field Emission Display

FEMA-PRISM .... Commercial Finite Element Code for Computational Electromagnetics

FET .... Field Effect Transistor

FFTV .... Fully Fielded Test Vehicle

FLC .... Ferroelectric Liquid Crystal

FMTV .... Family of Medium Tactical Vehicle

FOV .... Field of View

FPA .... Focal Plane Array

FPD .... Flat Panel Display

FPGA .... Field Programmable Gate Array

FSS .... Frequency Selective Surface

FXXILW .... Force XXI Land Warrior

FY .... Fiscal Year

FYDP .... Future Years Defense Plan

G&C.................... Guidance and Control

GaAs .... Gallium Arsenide

GaN..................... Gallium Nitride

GaSb.................... Gallium Antimonide

GBL .... Ground Based Laser

GBR..................... Ground Based Radar

Gbs...................... Gigabits (bytes) Per Second

GBS..................... Global Broadcast System

GCCS.................. Global Command and Control System

GEM.................... Generic Emulated Microcircuit

GEN-X................ Generic Expendable

GHz..................... Gigahertz

GLV.................... Grating Light Valve

GOTS.................. Government Off the Self

GPS..................... Global Positioning System

GPS..................... Global Positioning System

HABE.................. High Altitude Beam Experiment

HAST.................. Highly Accelerated Stress Testing

HBT.................... Heterojunction Bipolar Transistor

HDI..................... High Density Interconnect

HDMP................. High Density Microwave Packaging

HEMT................. High Electron Mobility Transistor

HF....................... High Frequency

HFET.................. Heterojunction Field Effect Transistor

HgCdTe.............. Mercury Cadmium Telluride

HIMARS............ High Mobility Artillery Rocket System

HIPP.................... Highly Integrated Packaging and Processing

HMD................... Helmet Mounted Display

Ho:YAG............. Holmium: Yttrium Aluminum Garnet

Ho;Tm:YLF........ Holmium; Tamarium: Yttrium Lanthanum Fluoride

HSOK.................. Hunter/Standoff Killer

HSS..................... Hunter Sensor Suite

HUMINT .... Human Intelligence
IADS .... Integrated Air Defense Simulation
IC .... Integrated Circuit
ID .... Identification
IDECM................ Integrated Defense Electronic Counter Measures
IEC .... Integration and Evaluation Center
IFF....................... Identification Friend or Foe
IIR .... Imaging Infrared
IMINT .... Imagery Intelligence
IMS .... Ion Mobility Spectroscopy
InAs..................... Indium Arsenide
InGaAs .... Indium Gallium Arsenide
InP .... Indium Phosphide
IPB .... Intelligence Preparation of the Battlefield
IPPD.................... Integrated Product and Process Development
IPR .... Intermediate Performance Review
IR .... Infrared
IRCM .... Infrared Counter Measures
IS .... Information Superiority
IS&T .... Information Systems and Technology
ISR .... Intelligence Surveillance and Reconnaissance
ISX...................... Information Superiority Experiment
IVHS .... Intelligent Vehicle Highway System
IW .... Information Warfare
IW-D .... Information Warfare - Defensive
J/S .... Jam to Signal Ratio
JAMC.................. Joint Amphibious Mine Countermeasure
JCAD .... Joint Chemical Agent Detector
JCOS .... Joint Countermine Operational Simulation
JCS .... Joint Chiefs of Staff
JCSE .... Joint Continuous Strike Environment
JDAM.................. Joint Defense Attack Munition

JDAM-3 .... Joint Direct Attack Munitions - 3

JEM..................... Jet Engine Modulation

JFET.................... Junction Field Effect Transistor

JHU..................... Johns Hopkins University

JL........................ Joint Logistics

JLENS................. Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System

JPL...................... Jet Propulsion Lab

JPO...................... Joint Program Office

JPO-BD.............. Joint Program Office for Biological Defense

JRAMS............... Joint Readiness Automated Management System

JROC.................. Joint Requirements Oversight Council

JSF...................... Joint Strike Fighter

JSIMS................. Joint Simulation System

JSTARS.............. Joint Surveillance Target Attack Radar System

JTAV.................. Joint Total Asset Visibility

JTMD................. Joint Theater Missile Defense

JTR..................... Joint Training Readiness

JV........................ 2010 Joint Vision 2010

JWARN.............. Joint Warning and Reporting Network

JWARS............... Joint Warfare Simulation

JWCA................. Joint Warfighting Capability Assessment

JWCO................. Joint Warfighting Capability Objective

JWE.................... Joint Warfighting Experiment

JWID.................. Joint Warfare Interoperability Demonstration

JWSTP............... Joint Warfighting Science and Technology Plan

KGD................... Known Good Die

KHz.................... Kilohertz

km....................... Kilometer

KTA.................... Potassium Titanyl Arsenate

LACMD............. Land Attack Cruise Missile Defense

LAD.................... Logistics Anchor Desk

LAD.................... Large Area Decontamination

LADAR............... Laser Radar

LAMP .... Large Aperture Mirror Program

LCAC.................. Landing Craft Air Cushion

LCPK .... Low Cost Precision Kill

LD .... Laser Diode

LEAP .... Lightweight Exo-Atmospheric Projectile

LEO..................... Lateral Epitaxial Overgrowth

LIDAR .... Light Detection and Ranging

$LiMnO_2$ .... Lithium Manganese Dioxide

LNA .... Low Noise Amplifier

LO .... Low Observable

LOCAAS .... Low Cost Autonomous Attack System

LOCAAS .... Low Cost Antiarmor Submunition

LODE.................. Large Optics Demonstration Experiment

LOS..................... Line of Sight

LPI .... Low Probability of Interception

LRF .... Laser Range Finder

LTCC .... Low Temperature Co-Fire Ceramic

LTD..................... Laser Target Designator

LWIR .... Long Wave Infrared

M&S .... Modeling and Simulation

MAC .... Month After Contract (Award)

MAFET.............. Microwave and Analog Front End Technology

MAJCOM .... Major Command

MBE.................... Molecular Beam Epitaxy

MC&G .... Mapping Charting and Geodesy

MCI..................... Multi-Chip Integration

MCM................... Multi-Chip Module

MCM................... Mine Countermeasures

MCM-C.............. Multi-Chip Modules - Ceramic

MCM-D .... Multi-Chip Modules - Deposited Thin Film

MCM-L.............. Multi-Chip Modules - Laminated

MCM-Si .... Multi-Chip Modules - Silicon

MCXO .... Microcomputer Compensated Crystal Oscillator

MEADS .... Medium Extended Air Defense System

MEMS................ Microelectromechanical Systems

MERS .... Multifunction Electromagnetic Radiating Systems

MESFET .... Metal Semiconductor Field Effect Transistor

MHDL................ MIMIC Handwave Description Language

MHK .... Mine Hunter Killer

MHz .... Megahertz

MICSTAR.......... Military Strategic Tactical Relay

MIM .... Metal Insulator Metal

MIMIC .... Microwave & Millimeterwave Monolithic Integrated Circuit

MITL.................. Man in the Loop

MLLD .... Mode Locked Laser Diode

MLRS .... Multiple Launch Rocket System

MLS .... Multilevel Security

mm .... Millimeter

MMACE .... Microwave/Millimeterwave Advanced Computational Environment

MMIC .... Microwave Monolithic Integrated Circuit

MMS .... Micro-Module Systems

MMT.................. Miniaturized Munition Technology

MMW................. Millimeter Wave

MNS................... Mine Neutralization System

MNS................... Mission Need Statement

MOCVD............. Metal Organic Chemical Vapor Deposition

MOE................... Measures of Effectiveness

MOPA................ Master Oscillator Power Amplifier

MOU .... Memorandum of Understanding

MOUT................ Military Operations in Urban Terrain

MPC .... Membrane Probe Card

mph .... Miles per Hour

MPM .... Microwave Power Module

MRC .... Major Regional Conflict
MRL.................... Multiple Rocket Launcher
MSCM .... Multi-Spectral Counter Measures
MSTAR............... Moving and Stationary Target Acquisition and Recognition
MTBF .... Mean Time Before Failure
MTI..................... Moving Target Indicator
MUDSS............... Mobile Underwater Debris Survey System
MURI.................. Multi-Discipline University Research Initiative
MW..................... Medium Wave
MW..................... Microwave
MWIR................. Medium Wave Infrared
NBC .... Nuclear Biological and Chemical
NCID................... Non-Cooperative Identification
NDI .... Non-Destructive Inspection
NEDT.................. Noise Equivalent Delta Temperature
NF .... Noise Figure
NIR...................... Near Infrared
NIST.................... National Institute of Standards and Technology
NLOS .... Nonlethal Operating System
NTM.................... National Technical Means
O&M................... Operations and Maintenance
ODDR&E............ Office of the Director Defense Research and Engineering
OEIC .... Opto-Electronic Integrated Circuit
ONR.................... Office of Naval Research
OPAMPS .... Operational Amplifiers
OPO .... Optical Parametric Oscillator
ORSMC .... Off Route Smart Mine Countermeasure
OSD .... Office of the Secretary of Defense
p-Si...................... Polysilicon
P^3I .... Preplanned Product Improvement
PAC-3 .... PATRIOT Advanced Capability 3
PAE..................... Power Added Efficiency

PCB..................... Printed Circuit Board

PCS .... Personal Communication System

PCs...................... Printed Circuits

P_d.................................... Probability of Detection

PDLC .... Polymer Dispersed Liquid Crystal

PDM.................... Program Decision Memorandum

PDR..................... Preliminary Design Review

PEBB .... Power Electronic Building Blocks

PEM .... Proton Exchange Membrane

PEM .... Plastic Encapsulated Microcircuit

PGMM .... Precision Guided Mortar Munition

PHEMT............... Pseudomorphic High Electron Mobility Transistor

P_k.................................... Probability of Kill

PL........................ U.S. Air Force Phillips Laboratory

PML .... Pulse Mode Laser

PMLCD............... Passive Matrix Liquid Crystal Display

POC..................... Point of Contact

POM.................... Program Objective Memorandum

PRCMRL............ Precision Rapid Counter Multiple Rocket Launcher

PRG..................... Program Review Group

PSA/TSA .... Pressure Swing Adsorption/Temperature Swing Adsorption

PSTS .... Precision SIGINT Targeting System

PWB.................... Printed Wiring Board

QFD .... Quality Function Deployment

QWIP .... Quantum Well Infrared Photodetector

R&D.................... Research and Development

R&M................... Reliability and Maintainability

RAA.................... Required Assets Available

RAID................... Reduced Array Inexpensive Disks

RAM .... Random Access Memory

RAMICS .... Rapid Airborne Mine Clearance System

RCS..................... Radar Cross Section

RDE .... Research Development and Engineering

RELTECH .... Reliability Technology

RF .... Radio Frequency

RFCM .... RF (Radio Frequency) Countermeasures

RFPI.................... Rapid Force Projection Initiative

RL .... U.S. Air Force Rome Laboratory

RLC..................... Resistor Inductors and Capacitors

ROIC................... Read Out Integrated Circuit

ROM .... Read Only Memory

ROSA.................. Reduced Oxide Soldering Activation

ROV .... Remotely Operated Vehicle

RTIC .... Real Time Information in the Cockpit

RV .... Re-Entry Vehicle

S&R .... Surveillance and Reconnaissance

S&T..................... Science and Technology

SA .... Situation Awareness

SAMS .... Surface to Air Missile System

SAR..................... Synthetic Aperture Radar

SARARM .... Sense and Destroy Armor

SARDA............... Secretary of the Army for Research Development and Acquisition

SATCOM............ Satellite Communications

SAVANT .... Standard Analyzer for VHDL

SAW.................... Surface Acoustic Wave

SBIR .... Small Business Innovation Research

SBIRS .... Space Based Infrared System

SBL .... Space Based Laser

SEAD .... Suppression of Enemy Air Defenses

SEB .... Staphylococcal Enterotoxin B

SEI .... Specific Emitter Identification

SERAT................ Structurally Embedded Reconfigurable Antenna Technology

SHARP .... System Oriented High Range Resolution Automatic Recognition Program

SHG .... Second Harmonic Generation

SiC .... Silicon Carbide

SiC/GaN............. Silicon Carbide/Gallium Nitride

SiGe .... Silicon Germanium

SIGINT .... Signals Intelligence

SIMOX............... Separation by IMplantation of OXygen

SINCGARS......... Single Channel Ground and Airborne Radio System

SIT .... Static Induction Transistor

SLM .... Spatial Light Modulator

SM-2 .... Standard Missile 2

SMT .... Surface Mount Technology

SMTS .... Space and Missile Tracking System

SN .... Sensors

SNR..................... Signal to Noise Ratio

SOF .... Special Operations Force

SOIC .... Small Outline Integrated Circuits

SORTS .... Status of Resources and Training System

SOW.................... Statement of Work

SRAM .... Static Random Access Memory

STAFF .... Smart Target Active Fire and Forget

STN..................... Super Twisted Nematic

STOW .... Synthetic Theater of War

STRICOM........... U.S. Army Simulation Training and Instrumentation Command

SUO .... Small Unit Operations

T/R .... Transmit/Receiver

TAB .... Tape Automated Bonding

TACAIR............. Tactical Aircraft

TAPSSTEM........ Training and Personnel Systems Science and Technology Evaluation Management

TARA.................. Technology Area Review and Assessment

TBM.................... Theater Ballistic Missile

TCXO.................. Temperature Compensated Crystal Oscillator

TD .... Technology Demonstration

TDA .... Tactical Decision Aids

TELS .... Transporter Erector Launcher System

Terops/sec .... 10^9 operations/second

THAAD .... Theater High Altitude Area Defense

TLAMs................ Tomahawk Land Attack Missiles

TMD.................... Theater Missile Defense

TN .... Twisted Nematic

TOC .... Tactical Operations Center

TPED .... Technology Panel on Electron Devices

TRADOC .... Training and Doctrine Command

TRADOC .... U.S. Army Training and Doctrine Command

TRP .... Technology Reinvestment Project

TSMD .... Time Stress Measurement Device

TSTB .... Tools for Synthesis of Test Benches

TTP .... Tactics Techniques and Procedures

TWMP .... Track Width Mine Plow

TWMR .... Track Width Mine Roller

TWS .... Threat Warning System

UAV .... Unmanned Aerial Vehicle

UFP .... Ultra Fine Pitch

UGS .... Unattended Ground Sensor

UGV .... Unmanned Ground Vehicle

UHF .... Ultra High Frequency (30-300 Mhz)

UJTL .... Universal Joint Task List

UPC .... Unit Product Cost

USMC .... United States Marine Corps

USSOCOM .... U.S. Special Operations Command

UUV .... Unmanned Underwater Vehicle

UV .... Ultraviolet

UXO .... Unexploded Ordnance

VCSEL .... Vertical Cavity Surface Emitting Laser

VCXO .... Voltage Controlled Crystal oscillator

VHDL .... VHSIC Hardware Description Language

VHDL-AMS .... VHSIC Hardware Description Language - Analog Microwave Simulator

VHF .... Very High Frequency

VHSIC .... Very High Speed Integrated Circuit

VLSI.................... Very Large Scale Integration

VLWIR .... Very Long Wave Infrared

VME.................... Virtual Memory Extension

VMF.................... Variable Message Format

VMMD................ Vehicle Mounted Mine Detector

VR........................ Video Recorder

VRD .... Virtual Retinal Display

VSPEC .... VHDL Specification

W......................... Watt

WATS .... Wide Area Tracking System

WAVES .... Waveform and Vector Exchange Specification

WL .... U.S. Air Force Wright Laboratory

WLBI .... Wafer Level Burn In

WMD .... Weapon Mounted Display

WMD .... Weapons of Mass Destruction

WORM................ Write Once Read Many (times)

X-ROD................ Kinetic Energy - Guided Munition

x-Si...................... Single Crystal Silicon

ZGP .... Zinc Germanium Phosphate